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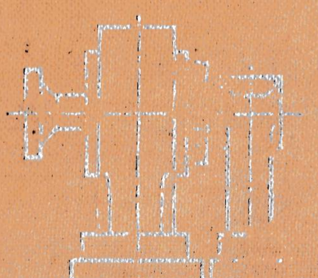
ELECTRICAL MACHINE INSTALLATION AND WIRING PRACTICE



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МОНТАЖ ЭЛЕКТРИЧЕСКИХ МАШИН

ИЗДАТЕЛЬСТВО «ЭНЕРГИЯ» · МОСКВА

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ELECTRICAL MACHINE INSTALLATION AND WIRING PRACTICE

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by

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The Russian Alphabet and Transliteration

А а a	К к k	Х х kh
Б б b	Л л l	Ц ц ts
В в v	М м m	Ч ч ch
Г г g	Н н n	Ш ш sh
Д д d	О о o	Щ щ shch
Е е e	П п p	ъ ''
Ё ё ë	Р р r	ы y
Ж ж zh	С с s	ь '
З з z	Т т t	Э э e
И и i	У у u	Ю ю yu
Й й y	Ф ф f	Я я ya

На английском языке

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Contents

This book covers methods of installation of medium-size and large electrical machines, their inspection and tests.

The electrical machines dispatched in an assembled condition are considered from the point of view of their packing and handling method.

The book also deals with hoisting and haulage facilities, fixtures and pieces of equipment, tools, instruments, and materials involved in the installation of electrical machines.

Brief information is given on tolerances and fits to be taken into account when mounting the electrical machines.

Recommendations are presented on how to make the electrical machines ready for installation, including their inspection, acceptance of foundation plates, and marking-out of basic axes.

A detailed description of the installation procedure of electrical machines delivered on site in a disassembled condition includes: the sequence of operations, setting and levelling of the bed plates and bearing pedestals, pre-installation tests of the rotor and stator, rotor fitting onto the stator, installation of a non-split stator, rotor mounting in the stator, installation of the rotor and stator in the case of a split stator, adjustment of gaps between the stator and rotor.

The book specifies, likewise, methods of installation of electrical machines delivered on site in an assembled condition, including the installation technique for electrical machines with segmental bearings.

Various types of coupling the electrical machine shafts to each other and to the shafts of other machines and mecha-

nisms are discussed along with the design features of separate types of couplings and their compensating abilities.

How to fit the half-couplings onto the shafts, how to align the shafts, and what types of alignment fixtures to use, these are also the questions under consideration.

The book contains data on the mechanical design and assembly of bearings, and the alignment of antifriction bearing shells in particular.

From the book you will know how to check and wire the electrical machine current-carrying parts, how to check the commutator for good surface and the brush gear for proper setting and adjustment.

Methods of drying moistened insulation of electrical machines are outlined and recommendations are given on how to recognize an electrical machine that can be placed in operation without drying its insulation.

Post-insulation checks, tests, trial start, and debugging of electrical machines are specified.

Finally, the book gives recommendations on the organization of labour and safety precautions to be observed during the installation of electrical machines.

Preface

A pronounced rise in the electrical installation technical standard has been achieved due to the industrialization of electrical installation and wiring technique, development and introduction of advanced technology, improvement of organization of labour, introduction of scientific organization of labour.

Backed up by a many-year experience, the installation technique has been greatly improved at separate operations; advanced methods are introduced in the preparatory work and installation procedure due to the creative initiative of innovators; further improvement and acceleration of electrical installation and wiring jobs is achieved on the basis of rationalization proposals; new tools, appliances, and mechanisms are developed to facilitate the installation work. The most complicated and important of all the electrical installation processes is the installation of medium-size and, in particular, large electrical machines. The construction of industrial installations and the terms within which they are placed in operation greatly depend on the skill of electricians engaged in installation, on the knowledge of up-to-date installation technique, methods of adjustment, on the knowledge of advanced methods, tools, accessories, instruments, and mechanisms.

The book is meant as a manual to be used by engineers and workers dealing with the electrical machine installation practice. It may be likewise useful for those engaged in the electrical machine installation and debugging to gain better skill in the job, as well as for the attending personnel of electrical machines in service.

The Preface, Chapters 1 through 8, 10 through 17, 20 through 21 have been written by M. Kaminsky, and Chapters 5, 9, 18, 19, 22 and 23, by V. Poluchankin.

CHAPTER ONE

General

1.1. Classification and Design Forms of Electrical Machines

The scope and content of installation work depend primarily on the power output, size, method of shipment, and design form of the electrical machines.

According to their *power output* the electrical machines are classified as low-power (up to 100 kW), medium-power (from 100 to 1000 kW), and heavy-power or large electrical machines (1000 kW and higher or 500 kW and higher for low-speed machines).

The machines may be furnished either with outboard or endshield bearings depending on their output, size, and purpose.

Low-power and most medium-power electrical machines are fitted with antifriction (ball and roller) bearings while medium-power low-speed and heavy-power electrical machines usually rotate in sleeve bearings.

The electrical machine *size* depends on its power output and speed of rotation. The latter is inversely proportional to the machine size and mass.

Methods of shipment depend on the power output and size of the machines which may be delivered to the site of installation either fully assembled or disassembled.

In order to meet railway transport limitations, as far as the loading gauge is concerned, large electrical machines are delivered, in most cases, in a disassembled condition. Moreover, large low-speed machines have split stators to facilitate their handling and erection on site.

Direct-current machines may have split stators at a power output of 500 kW and heavier. Splitting of stators in alternating-current machines is hampered by the necessity of splitting the iron cores which are built up of separate stam-

pings or segments. Therefore, alternating-current machines are made with split stators only when their power output is more than a few thousand kilowatts.

The electrical machines furnished with pedestal bearings mounted on separate bed plates are usually delivered in a disassembled condition.

Motor-generator sets composed of two or more machines may be dispatched in an assembled condition on a common bed plate with aligned shafts provided they meet the limitations of the clearance gauge.

Direct-current machines incorporated in motor-generator sets as well as synchronous machines driving compressors or large pumps are delivered with one pedestal bearing.

Low-speed synchronous motors of direct-driven piston compressors are delivered with disassembled rotors which are fitted on the compressor shaft in situ.

Low- and medium-power electrical machines are shipped from the manufacturing plants, as a rule, in an assembled condition. Sometimes they are delivered to the User on a common bed plate and aligned with the driven machines or mechanisms (motor-generator sets, motor-pump plants, etc.).

According to the forms of design, the electrical machines are divided into eight groups. The code designation of each group is given in Table 1.1.

Groups M1, M2, M3, M4, and M5 include low- and medium-power electrical machines.

Group M5 includes primarily low-power built-in or built-to electric motors, such as those built in power-driven tools, cutting machines, etc. These machines are not dealt with in the book.

Large machines are made with pedestal bearings and classified as groups M6 and M7. Each of these groups is subdivided into five alternates coded, respectively M60, M61, M62, M63, M64 and M70, M71, M72, M73, M74.

The group M6 machines, in their turn, are available of two design forms, *viz.* machines without a bed plate (designated with numeral 1) and those with a bed plate (bearing numeral 2 in their designation). The group M7 machines are available of three design forms, *viz.* machines without a bed plate (designated with numeral 1), machines with a

Table 1.1

Code Designations of Electrical Machine Groups

Code designations	Description
M1	Foot-mounted, axle-hung, pivoted machines with two (or one) end shields and a built-to reduction gear
M2	Foot-mounted machines with two end shields and a flange end shield. The centring notch on the flange is made at the shaft extension end
M3	Footless machines with a flanged end shield, bedframe-mounted
M4	Footless machines with a flanged face-mounted frame
M5	Built-in (built-to) machines
M6	Foot-mounted machines with end shields and pedestal bearings
M7	Foot-mounted machines with pedestal bearings
M8	Heavy-power vertical-shaft machines

bed plate (designated with numeral 2) and machines with separate bed plates (bearing numeral 3 in their designation).

The code designation of each machine comprises three numerals. For instance, in the M612 designation, the first numeral indicates the group (M6), the two numerals show the design alternate (M61), and the three numerals give the design form of the machine, numeral 2 indicating that the machine has a bed plate.

The design form of motor-generator sets bears in its designation the codes of the separate machines incorporated in the set (for instance M702-M732).

The most widely used design forms are as follows: M602 and M702 (machines with a single pedestal bearing mounted on a common bed plate and a flanged shaft extension); M631 and M731 (machines with two pedestal bearings and a shaft extension, without a bed plate); M632 and M732 (machines with two pedestal bearings mounted on a common bed plate, and with a shaft extension); M788 (machines with two pedestal bearings mounted on separate bed plates, with a shaft extension).

Figure 1.1 illustrates the most widely used forms of design of large electrical machines.

The electrical machines may have cylindrical, tapered, and flange-type shaft extensions. In the case of machines with two shaft extensions the shapes of the latter may be either identical or different (a combination of those indicated above), such as a flange-type and a tapered shaft

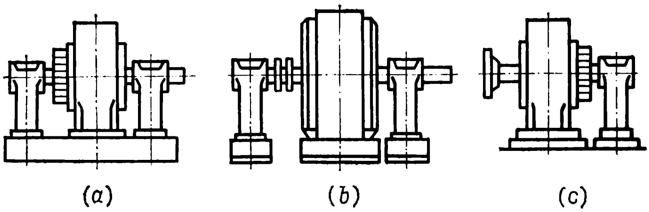


Fig. 1.1. Design forms of large electrical machines

(*a*) with two pedestal bearings mounted on a common bed plate; (*b*) with two pedestal bearings mounted on separate bed plates; (*c*) with one pedestal bearing

extensions, a cylindrical and a flange-type ones, or a cylindrical and a tapered shaft extensions. The code designation of the design form bears additionally a suffix showing the number and shape of the shaft extensions (Table 1.2).

Besides the above-described classification of the electrical machines according to their design forms, the machines are also classified according to the type of enclosure protecting

Table 1.2

Code Designations of the Shapes of Electrical Machine Shaft Extensions

Shaft extension shape	Designation	
	in case of one shaft extension	in case of two shaft extensions
Cylindrical	—	ZZ
Tapered	K	KK
Flange-type	F	FF
Flange-type and tapered	—	FK
Cylindrical and flange-type	—	ZF
Cylindrical and tapered	—	ZK

them against mechanical damage, dust, and moisture, methods of cooling and delivery of cooling air. The effect of these design features on the scope and content of electrical machine installation work is not so great as the effect of those described above.

According to the enclosure protecting the electrical machines against mechanical damage, dust, and moisture, the electrical machines are available of the open, totally enclosed, and protected types as well as those with protected slip rings.

An open-type machine does not feature any protection against accidental contact with rotating and live parts, nor is it protected against penetration of foreign bodies inside the machine. Machines of this type may be installed in enclosed premises only and serviced by specially trained personnel.

A totally *enclosed machine* is protected against penetration of dust by means of side end plates.

A protected machine is fitted with facilities protecting it against accidental contact with rotating and live parts, as well as against penetration of foreign objects and water drops. A machine of this type is not protected against dust, moisture and gases.

A machine with *protected slip rings* has a special detachable metal housing closing the slip rings.

According to the type of cooling, the electrical machines are classified as naturally cooled, self-cooled, externally self-cooled, and separately cooled.

Naturally cooled machines are not furnished with any cooling facilities. *Self-cooled machines* are provided with a cooling fan built integral with the rotating part of the machine. *Externally self-cooled machines* have their external surface cooled with surrounding air, while the winding-and-core assembly is totally enclosed and surrounding air is not admitted therein. *Separately cooled machines* are cooled with air delivered from a separate arrangement in which it is cooled down and forced to the machine with a fan. Hydrogen-cooled machines belong to this type.

According to the delivery of cooling air, the electrical machines can be furnished with an open-circuit or closed-circuit cooling system. In the former case, cooling air is drawn in from the outside, forced by a fan through the machine

and exhausted into the atmosphere. In the latter case, the machine is cooled with air of constant volume circulating between its interior parts and surface water coolers.

The cooling air must be dry, i.e. its relative humidity must not exceed 70 per cent.

Large turbogenerators are often cooled with hydrogen which affords approximately a ten-fold reduction in windage loss as compared with the air-cooled machines. As a result, the efficiency of such a machine is naturally higher. Heat conductivity and specific heat of hydrogen are, respectively, 7 and 14 times as high as those of air. The mass of a hydrogen-cooled machine reduces per every 1 kW output.

The installation and wiring of hydrogen-cooled machines is characterized by some peculiar features. The first one is the requirement for a more reliable sealing of joints as the penetrating power of hydrogen is four times as high as that of air. To prevent air from penetrating inside, hydrogen is maintained within the machine at a gauge pressure of 0.0035 MPa.

Hydrogen purity must be about 95 per cent in which case this gas is explosion-proof. At a purity below 75 per cent an explosive mixture is formed inside the machine. That is why, special safety precautions shall be observed when filling the machine with hydrogen or discharging the latter from it. The machine can be filled with hydrogen by two methods:

(a) air is displaced from the machine with carbon dioxide and the latter is replaced with hydrogen;

(b) air is forced out of the machine till a pressure one fifth below atmospheric is obtained inside, after which hydrogen is introduced directly into the machine. A hydrogen-air mixture at such a low pressure is nonexplosive.

1.2. Mechanical Design and Construction of Electrical Machines

The electrical machines are widely used in all branches of national economy. Medium-size and large electrical machines find application in mechanical engineering to drive large blowers and compressors, heavy-power metal-cutting machine tools, heavy conveyer lines; in mine industry to

drive mine hoists, large pumps, compressors, blowers, and other installations; in metallurgy to drive rolling mills.

Large electric motors are employed in steam power stations to drive circulating, feeding, condensate-removal, and power oil pumps, as well as ball mills. Squirrel-cage induction motors are most frequently utilized as they are noted for simple maintenance and reliable operation. More complicated slip-ring induction motors are used where speed control is essential, such as in hoists, reloaders, etc. Along with induction motors, use is also made of synchronous motors for driving high-power mechanisms of steam power plants, such as feeding pumps and ball mills. These machines are more expensive than the induction motors, but their operational cost is cut down due to lower power loss both in the motors proper and in the power transformer.

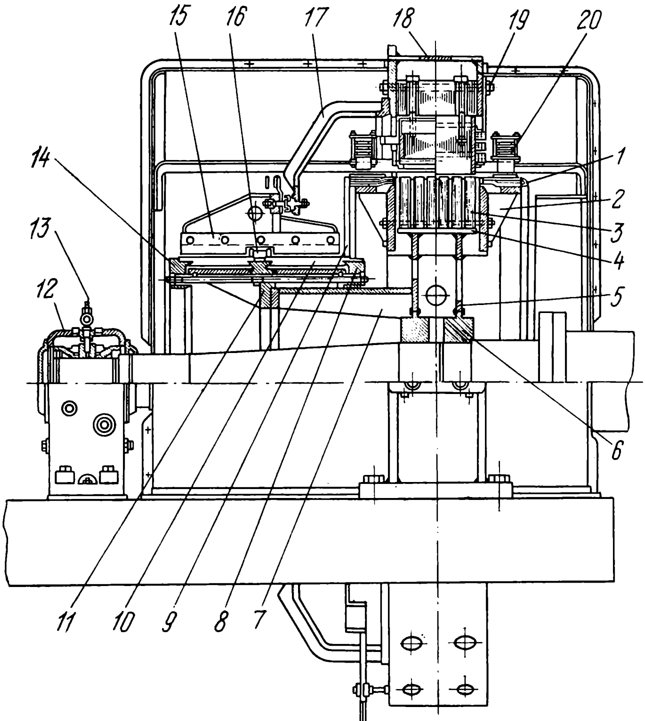
Given below are the mechanical design features of the most widely used medium-size and large direct-current machines, induction motors, and synchronous machines which may be essential to those dealing with the installation and wiring of these electrical machines.

The direct-current machines are constructionally most complicated electrical machines, because they comprise such complex parts as a commutator, a brush gear and an armature winding, and feature complex commutation processes, which necessitates their adjustment after installation and wiring. These machines may be entrusted in operation to qualified personnel only.

In some industries, the direct-current generators have been recently displaced by mercury-pool, silicon, and thyristor converters. The direct-current motors, however, are in common use as drives of rolling mills and other metal-working pieces of equipment, as well as of some types of home power sets in steam power stations, due to their significant properties, such as stepless speed regulation within a wide range.

The medium-size and large direct-current machines are available in standard ranges. The electrical machines of 160 to 1500 kW output have armatures of 423 to 990 mm in diameter. Those of 1500 to 5400 kW output have an armature diameter of 2150 to 3800 mm and are built up of separate segments.

A smooth starting and speed regulation within a wide range for driving the rolling mills is afforded through the use of the so-called adjustable-speed or Ward-Leonard system



(a)

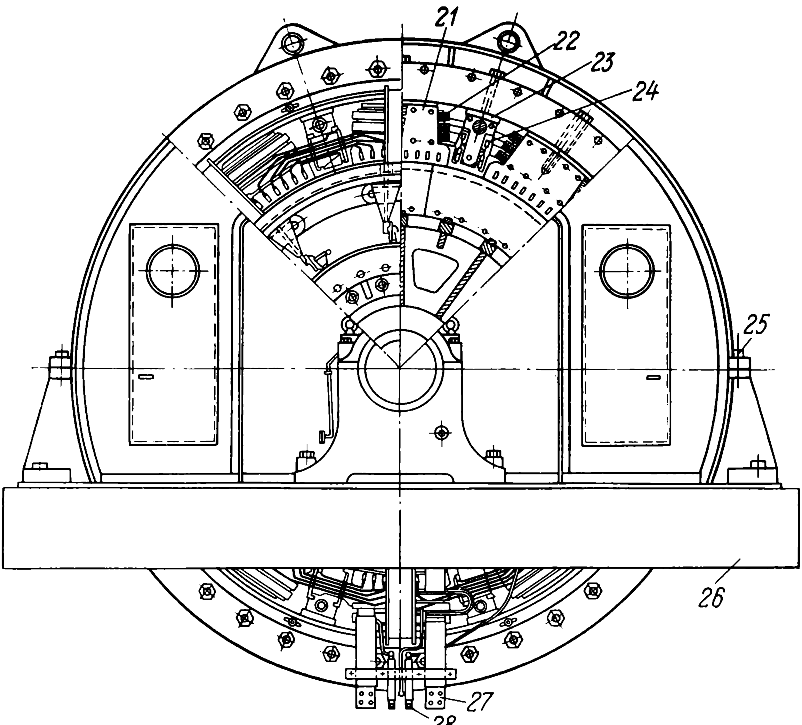
Fig. 1.2. Direct-current

(*a*) front view; (*b*) side view; *1* —end windings; *2*—end plate; *3*—armature coil; *10*—commutator bars; *11*—bush; *12*—sleeve bearing; *13*—pipe; *15*—bracket; pensating winding; *21*—main poles; *22*, *24*—coils; *23*—commutating poles;

which consists of a *dc machine* Series П running as a generator, and one or more induction motors, such as Series AT. A dc generator, size 21, is illustrated in Fig. 1.2. The generator shaft has a flange at the end which is bolted to the drive motor shaft to make a rigid connection. The generator is fitted with a pedestal sleeve bearing *12* and another bearing

mounted on its shaft. The bearing is lubricated by means of two oil-control rings and an oil pump through pipe *13*.

The pedestal bearing and the frame feet are mounted on a



(b)

machine, Series П

4—key-bar; *5*—disc; *6*—hub; *7*—bracket; *8*, *14*—washers; *9*—commutator risers; *16*—connecting strip; *17*—brush rocker; *18*—cover plate; *19*—studs; *20*—com- *25*—bolt; *26*—bed plate; *27*—strip; *28*—binding post

common bed plate *26*. The machine bottom part is flush-mounted in the plate recess to reduce its elevation above the floor level. The stator winding leads are also arranged at the bottom of the stator frame. The armature winding leads are made of strips *27* and the shunt-winding leads are brought out in the form of binding posts *28*.

The machine interior is separated from surrounding atmosphere with a sheet-steel "wrapper" casing. The machine is cooled by air delivered from a separate cooling plant. Cooling air is admitted through ports on the commutator end of the "wrapper" casing and discharged through ports on the opposite side.

A machine of this design has its magnetic flux closed through the yoke and not through the field frame. The yoke is built up of segments clamped with studs *19* between the end plates of a fabricated frame, the latter being protected from the outside with a sheet-steel cover plate *18*. The frame has a split at the horizontal line and both its halves are clamped together with bolts *25*. Bolted to the yoke are main poles *21* and commutating poles *23* carrying coils *22* and *24*, respectively. Slots are stamped in the pole shoes to accommodate the bars of compensating winding *20*.

The armature core is assembled of segments located and built on key-bars *4* and clamped with studs between end plates *2*. The armature slots accommodate a bar winding. End windings *1* are held on winding supports.

Since the dc machines of this type may be rated at a voltage as high as 1000 V, the armature current of 1500-kW and larger machines is rather high and may reach a few thousand amperes, which makes it necessary to build a commutator as long as 1 metre. In order to avoid sagging of the commutator bars under the effect of centrifugal forces, such machines are furnished with a twin commutator.

Commutator bars *10* are welded together by means of copper strips *16*, are assembled on a common bush *11*, and clamped with common studs between pressure washers *8* and *14*.

The commutator bush is bolted to bracket *7* of the armature spider. Such an arrangement prevents the shaft vibrations from passing over to the brushes and makes it possible, during repairs, to remove the shaft without unsoldering the armature winding leads from commutator risers *9*.

The brushes are inserted in the brush holder boxes fixed on brackets *15*. The latter, in their turn, are secured to brush rocker *17* through insulating gaskets. The like-polarity brackets are interconnected by means of two slip rings arranged over the former. The brush rocker is free to turn for setting the brushes to the correct neutral.

The armature spider consists of hub *6* press-fitted on the shaft and carrying two discs *5* with radial ribs welded to them inbetween. The external surfaces of the discs carry key-bars for centring the armature core segments. The armature core is divided by cooling ducts into six stacks, which improves the cooling conditions. Distance plates provided between the armature stacks are used as centrifugal fan blades which force the cooling air through the ducts between the armature stacks when the armature is rotating.

The air gap between the armature and the poles is adjusted by means of shims inserted between the poles and the yoke. A uniform air gap throughout the entire circumference is obtained during the machine installation on a bed plate by placing adjustment shims under the bearing pedestals.

Induction motors. The induction motors of 1000 kW and larger output are made in sizes ranging from 16 to 20. The stator and rotor cores of these machines are built up of segments, the stator frame is a fabricated structure. According to the type of enclosure, the motors may be either open or protected. According to the form of design, they are made with two pedestal bearings on a bed plate.

Taken as an illustration for the description of the construction of the induction machines is the most widely used motor of the AT series, size 19 (Fig. 1.3) employed for heavy-power drives in metallurgy, coal industry, mechanical engineering, and other branches of industry (rolling mills, mine hoists, pumps, fans, and other mechanisms). The electric motors of this series are available at voltages of 3000 and 6000 V.

Splitting of the stator frame in the three-phase machines causes difficulties connected with the alignment of the stator core halves. That is why these machines are split only in case their size does not meet railway transport limitations. The series AT motor has a non-split fabricated frame consisting of three rings *8* welded to an external wrapping plate *6*. The required rigidity of construction is obtained by means of ribs *5* welded inbetween the rings. These ribs serve, at the same time, as supports for locating and building up the stator segments. The latter are press-fitted between the ring and the swivel plate provided on the opposite

end of the stator, and the whole assembly is braced together by means of studs passed through the entire core length. Strips *7* are welded to the stator ribs to prevent the studs from sagging.

The stator core slots accommodate the winding coils. The end windings are tied with a cord to bands *10* which are

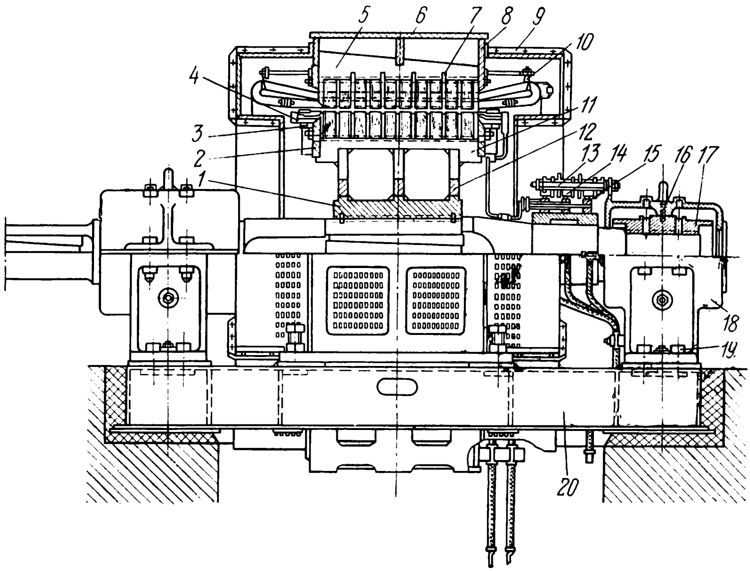


Fig. 1.3. Induction motor, Series AT

1—hub; *2*—end plate; *3*—winding support; *4*, *7*—strips; *5*—ribs; *6*—wrapping plate; *8*—ring; *9*—casing; *10*—band; *11*—key-bar; *12*—disc; *13*—brush spindle; *14*—brush holder; *15*—slip rings; *16*—bearing crown; *17*—bearing shell; *18*—bearing pedestal; *19*—pin; *20* — bed plate

screwed into the end plate. Casing *9* protects the winding from the ingress of foreign bodies.

The stator frame and the bearings are mounted on a concrete foundation on a common bed plate *20* which is grouted in cement after the machine is installed and the shafts are aligned. The stator winding leads are brought out and placed in a recess provided in the bed plate at the frame bottom.

The spider of the series AT motors consists of a solid steel hub *1* and three discs *12* with air outlets. The discs are

ring-welded to the hub. Wide longitudinal key-bars *11* are welded to the discs. The rotor core is built up of segments. Each segment has two keyways and two holes. The latter receive studs which compress the core and hold the segments in position to prevent their displacement under the effect of centrifugal forces.

The spider ribs mount end plates *2* and winding supports *3* welded to the former. The bar winding is held in the slots with fabric-base laminate wedges. The end portions of the bar winding are secured with steel wire bands. Hub *1* is press-fitted on the stepped middle portion of the shaft.

Slip-rings *15* are press-fitted on a cast-iron bush covered with paper-base laminate insulation. The slip rings mount brushes placed in brush holders *14* which are carried by insulated brush spindles *13*.

The shaft journals are supported by two pedestal sleeve bearings. Bearing crowns *16* and shells *17* are split structures, which facilitates the machine erection on the bed plate. Bearing pedestals *18* are attached to the bed plate with four bolts and locked in position with bevel pins *19* to facilitate the pedestal mounting.

Synchronous machines may be employed as generators and as motors. Synchronous generators are used in small-power plants (of a few hundred or a few thousand kilowatt output) feeding timber mills and construction sites, as well as in other fields of national economy. They can be likewise employed in medium and large-power plants.

Synchronous motors have found application where frequent starts and speed variation are not required, such as for driving fans, pumps, compressors, and other mechanisms. As has been stated above, they are more complex machines than induction motors as far as their mechanical design and maintenance are concerned. Besides, they require a dc power source or a built-in exciter for feeding the field windings. On the other hand, they feature a valuable property: draining no magnetizing current lagging behind the voltage from supply mains, they moreover return to supply mains the leading capacity current. Such an ability of synchronous motors improves the power factor ($\cos \varphi$) of the system.

Synchronous machines of a simpler construction have recently found wide application. These machines are excited

by permanent magnets, or solid-state rectifiers are used to feed their field windings.

All the synchronous machines are physically constructed as salient-pole or nonsalient-pole (distributed-field) machines. Salient-pole machines are available in a speed range from a few scores to 1500 r/min. Nonsalient-pole machines are mostly available for a speed of 3000 r/min. These are all the turboalternators and high-speed motors (the so-called turbomotors).

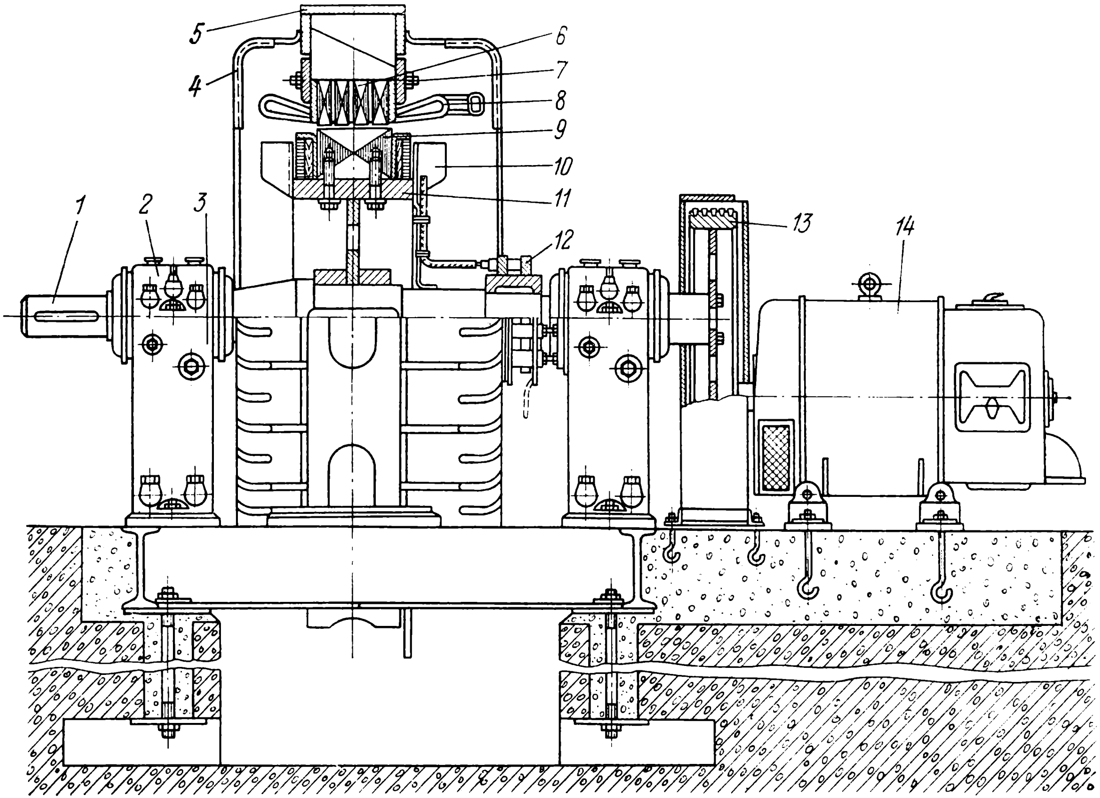
The three-phase synchronous machines of 320 to 10 000 kW output and the induction motors are manufactured in a common standard series of sizes ranging from 14 to 20, which appreciably cuts down their manufacturing cost as most parts, such as stators, bearing units, bed plates, are made identical for the synchronous and induction machines. The standard-series synchronous generators and motors bear type designations СГН and СДН, respectively. Non-split fabricated sheet-steel frames are used for size 14 through 19 machines while those of the size 20 machines have a split at the horizontal line.

The size 14 through 20 synchronous machines are excited by the series ПВ dc generators which are directly coupled with the machine shaft (machines running at 600 to 1000 rpm) or through a V-bolt drive (those running at lower speeds).

Figure 1.4 illustrates a series СГН 500 rpm generator. Stator core *6* of this machine is clamped with studs *7* within a non-split fabricated frame *5*. The coils of winding *8* are placed in the open stator slots. The end windings are protected with casing *4*.

Rotor spider *11* is also a fabricated structure. Poles *9* carrying coils and fan blades *10* are bolted to the spider rim. The coil leads are brought out to slip rings *12* press-fitted on shaft *1*.

The rotor shaft is mounted in two sleeve bearings provided with split crowns *2* and shells. Sleeve bearing pedestals *3* are mounted together with frame *5* on a common bed plate. Exciter *14* and the generator are mounted on a common foundation and their shafts are joined through V-belt drive *13*. Figure 1.5 shows the general view of the series СДН 1000 r/min motor. Exciter *3* is mounted on support *4*. The exciter shaft is joined to the motor rotor via coupling *5*.



1
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The dc voltage generated by the exciter is applied to the rotor winding via brush holders fixed on arc yokes *6*. The stator winding of the motor is covered with casing *2* which is built up of separate segments.

The machine is cooled by air forced through its interior by means of a fan. The cooling system used in the machine of this design is of a double-ended radial type. Cooling air

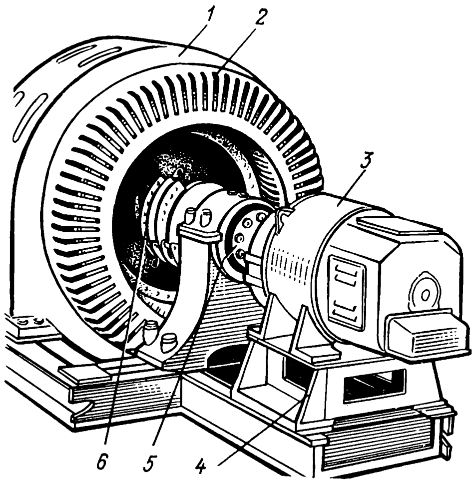


Fig. 1.5. Synchronous motor, Series СДП
1 — motor; *2* — casing; *3* — exciter; *4* — support; *5* — coupling; *6* — yoke

enters the ducts between the rotor field coils on both sides of the machine, passes through radial cooling ducts of the stator core and is discharged through ports in the stator wrapping plate.

Used as drives of high-speed mechanisms (pumps, turbocompressors, etc.) are nonsalient-pole synchronous motors, such as the series СДБ 3000 r/min machine illustrated in Fig. 1.6. Motor *1* and exciter *3* are mounted on a common bed plate *4*, and the shafts of both the machines are joined with flexible coupling *2*. The rotor core is forged integral with the shaft from a single steel piece. The rotor core (barrel) has milled slots accommodating a concentric field winding.

To prevent the effect of heavy centrifugal forces, the end windings are held in position with solid steel bands and not with wire bands. The steel bands are shrunk while hot during the motor manufacture.

Large electrical machines are usually furnished with babbit-lined sleeve bearings, either ring-oiled or force pressure-lubricated. Branched lubricating systems afford the required amount of oil for the machines. Such lubricating systems are provided with pumps, oil-cleaning machines, oil

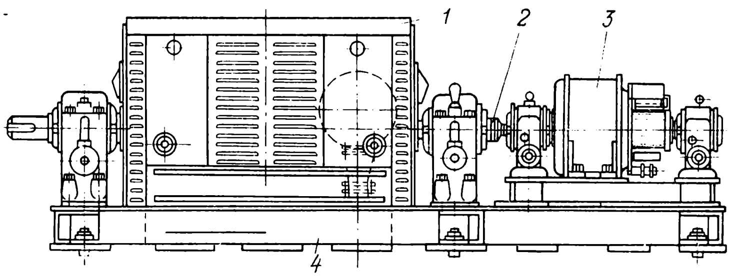


Fig. 1.6. Synchronous motor, Series СДБ
1 — motor; *2* — flexible coupling; *3* — exciter; *4* — bed plate

coolers, and, sometimes, oil heaters. Oil is renewed in ring-lubricated bearings after every 200 or 300 hours of operation and at least once every 3 to 6 months.

In a force pressure-lubricated machine, an oil pressure of 0.025 to 0.05 MPa must be maintained in front of the bearing; the inlet oil temperature, at the moment the machine is started, must not be lower than 30°C. It shall be borne in mind that at a lower temperature of inlet oil the bearing shell may seize at starting due to excessive viscosity of cool oil. The temperature of outlet oil of a running machine is to be 35-40°C and must never exceed 55-60°C. If the delivery tank surface is insufficient to provide for air cooling of the oil, use is made of water coolers.

The oil cooler is rated at an oil temperature drop of 15-20°C, the cooling water temperature drop within the oil cooler being 10-15°C.

The delivery tank may be furnished with special heaters of 1-kW power for 500-litre tanks and 2-kW power for

1000- or 1500-litre tanks to heat the oil to a temperature of 30°C.

The types and grades of oil to be used for ring-lubricated or force pressure-lubricated sleeve bearings are usually specified by the Manufacturer of the machines.

Exciters, drive motors of auxiliary machinery, as well as some large electrical machines are fitted with ball or roller bearings which are packed with grease at the manufacturing

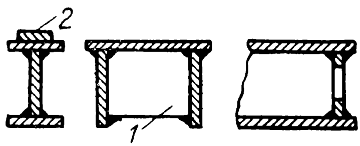
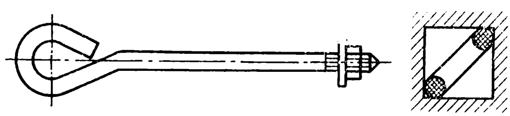


Fig. 1.7. Sectional views of bed plates
1 — stiffening rib; 2 — supporting plate

plant. Universal medium-heat grease (solid oil) or high-heat grease (1-13 or konstalin) is usually introduced in antifriction bearings.

The bed plates of large electrical machines and motor-generator sets may be either common or separate for each



(a) (b)

Fig. 1.8. Hook-type foundation bolt
(a) bolt; (b) anchor hole

separate item, this depending on the size of the machines. The plates are fabricated from thick sheet steel or I-section bars and large beams. The desired rigidity is obtained by welding special ribs to the plate walls.

Figure 1.7 shows the sectional views of the bed plates. Supporting plates specially cut on the top to mount the bearing pedestals and the machine frame may be welded to the bed plate, which makes the latter easier to manufacture.

The bed plates may be of a rectangular shape (for mounting motor-generator sets, machines with two pedestal bearings) or U-shaped for mounting machines with a single pedestal bearing. The bed plates are secured to the foundation with anchor bolts which may be either hook-type or with anchor plates.

The hook-type bolts are used for comparatively small-power machines. The length-to-diameter ratio of the hook-type bolts used for light-duty machines should be 20 and that for heavy-duty machines, 40 at a length of up to 2000 mm (Fig. 1.8).

The bed plates of large electrical machines are usually fastened by means of anchor bolts with anchor plates (Fig. 1.9). Such bolts measure up to 90 × 3500 mm at a mass of 175 kg and are installed by means of hoisting mechanisms. The bolts are threaded on both ends or on one end. In the latter case, the other end is fitted with a prismatic head. The anchor plates are made, in most cases, in the form of steel square strips or, sometimes, are cast of iron.

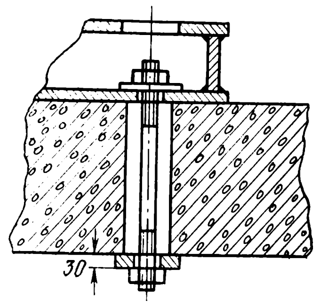


Fig. 1.9. Anchor bolt and anchor plate

The anchor bolts are usually furnished by the Manufacturer complete with the electrical machine. In the event anchor bolts are not included in the standard equipment, they can be manufactured on site (provided all the necessary pieces of equipment for their manufacture are available), in compliance with reference drawings and instruction sheets supplied by the Manufacturer or Designer.

CHAPTER TWO

Packing and Shipment of Electrical Machines

2.1. General

The Manufacturer's packing of electrical machines or their separate parts may be of an open, semi-open, or enclosed type.

The open packing protects the electrical machine or its separate parts against mechanical damage and dirt, facilitates transportation and storage of the machine, but does not protect it against the effect of surrounding atmosphere (rain, snow, etc.). The open packing may be used when the item transported is of a sufficiently robust construction to take mechanical thrusts in transit and is proof of corrosion or other atmospheric effects. This type of packing is also suitable for items subjected in the course of their manufacture to a special treatment protecting them against injury (including corrosion-preventive treatment).

Such are totally enclosed outdoor induction motors which are delivered to the User in an open-type packing on wooden skids. In the recent years some Manufacturers use the open-type packing for totally enclosed indoor machines.

The semi-open packing ensures a partial protection of electrical machines or their separate parts against mechanical damage and the effect of surrounding atmosphere, and facilitates their transportation. With this type of packing the electrical machines or their parts are mounted on wooden skids or on a support made of wooden bars, covered on the top and sides with tar paper or ruberoid and boards, and then are fixed tight in position.

The enclosed packing fully protects the electrical machines or their separate parts against mechanical and atmospheric effects, and facilitates transportation of each piece of freight. The electrical machines or their parts are packed in robust crates suitably lined and covered with a water-

or vapour-tight material. Such type of packing is made by the Manufacturer for shipping the armatures and stators of dc machines as well as the open-type machines.

Heavy items, such as medium-size and large electrical machines, as well as their units and parts, are packed with utmost care. The packing arrangement depends on the mass, shape, rigidity, and other features of the item supplied. Heavy items of an irregular form need a particularly thorough fixation. In the action, measures are taken to avoid heavy local thrusts on the packing; to this end, the item is secured to the bottom of the crate or to supports, and contacting surfaces between the item and the packing are made larger.

Mounting plates (including the bed plates), feet, and other parts can be used for better fixation of the machine within the packing container and on transport facilities.

Most items are secured on the bottom of the packing crate. This method provides for the protection of the item against shocks as a clearance is provided on all the sides but one between the packing container and the item, which makes the latter immune to the diagonal strain of the external packing when shocks are absorbed. In this case, the bottom of the crate must be made sufficiently strong.

All the types of packing meant for large electrical machines and their components have a number of characteristic features and are defined by the condition of transportation.

2.2. Packing of Electrical Machines Shipped in an Assembled Condition

When electrical machines are dispatched to the User in an assembled condition, the cost of their packing is cut down due to a smaller quantity of packing facilities and materials, a lower amount of labour required for their packing and erection on site.

In connection with this, the Manufacturers dispatch electrical machines and their components in a disassembled condition only to meet transport limitations as to their size and mass, or to avoid damage to the machine parts, such as segmental bearing shells whose precision setting may be disturbed in transit.

Particular care shall be taken when packing electrical machines with antifriction bearings which are fixed in position and support the rotor in transit. This causes dents on the bearings due to jolts.

Manufacturers take measures to protect the antifriction bearings against damage when machines are shipped in an assembled condition.

Machines dispatched assembled over a distance exceeding 1000 km are shock-mounted and, when mounted on transport facilities, they are placed so that the machine axis is set across the transport motion direction. If the machine size does not allow it to be mounted in this way, use is made of various retainers which take loads on the bearings.

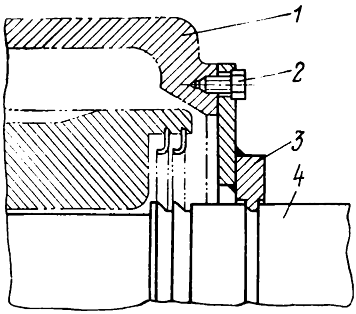


Fig. 2.1. Mounting the circular retainer in bearing

1 — bearing; 2 — bearing packing bolt; 3 — circular retainer; 4 — machine shaft

Up till recent time medium-size and large machines with pedestal sleeve bearings were packed and dispatched to the User with the rotor (or armature) removed. Sometimes, the machines were shipped fully assembled with the rotor fixed in position at a distance from the bearings by means of clamping arrangements which were secured to the bearing housing with the bolts of the bearing cap. The clamp was fixed to the rotor shaft with a bolt inserted in a threaded hole on the butt end of the shaft. Such clamps were suitable only for machines of a particular mechanical design. Their standardization was impossible, and they were not designed to take heavy axial inertia which may reach a magnitude equal to the rotor mass.

A universal circular retainer (Fig. 2.1) has been recently developed and is now widely used for fixing the rotor in transit. This retainer is made in the form of a combination ring having a lug, which enters a keyway on the rotor shaft, and a hole for fastening it on the bearing housing. The retainer is fitted in place of the bearing labyrinth.

The retainer is mounted in the oil slinger groove on the

rotor shaft. The semi-rings of the retainer are joined on the rotor shaft so that the lug enters the keyway and then they are bolted to the bearing housing.

The circular retainer size does not exceed that of the labyrinth rings, which makes such a retainer universal. The retainer sectional area is determined with due account for the torsional strength at axial thrusts equal to the rotor

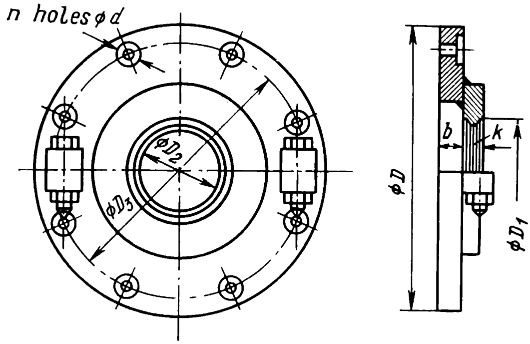


Fig. 2.2. Standardized circular retainer

mass, which is in full compliance with Shipping Specifications of the Ministry of Transportation.

In addition to the fixation of the rotor in transit, the retainer prevents dirt from getting inside the bearing. The circular retainer for electrical machines with pedestal sleeve bearings (standardized and non-standardized ones) is standardized as to its mechanical design and size (Fig. 2.2). Table 2.1 specifies sizes of standardized circular retainers.

With the advent of a circular retainer it has become possible to pack and dispatch in an assembled condition medium-size and large electrical machines with one pedestal bearing.

The electrical machines fitted with one pedestal sleeve bearing mounted on a bed plate are to be made ready for packing following the procedure given below. Prior to a final assembly, the machine parts are thoroughly examined and given a preservation treatment. An extension shaft is bolted to the rotor flange on the non-bearing side of the machine with one bearing. To prevent radial displacement of the rotor, the latter is held in position with spacers placed

Table 2.1

D, mm	D_1, mm	D_2, mm	D_3, mm	b, mm	n	d	Mass, kg	Maximum mass of armature (rotor), t
260	126	115	205	16	8	11	6.0	3.5
270	136	125	205	16	8	11	6.4	4.0
280	146	135	215	16	8	11	6.8	4.5
290	156	145	225	16	8	11	7.0	4.5
290	156	145	230	16	8	11	7.0	5.0
300	156	145	235	16	8	11	7.2	5.0
310	166	155	245	16	8	11	7.6	6.0
310	176	165	255	16	8	11	7.6	6.5
350	191	180	300	18	12	13	9.7	7.0
360	211	200	305	18	12	13	10.2	8.0
380	231	220	315	18	12	13	11.0	9.0
400	251	240	335	18	12	13	11.4	10.0
440	261	250	385	18	12	13	11.9	11.0
490	311	280	405	18	12	13	12.5	12.0

Note. Dimension k equals 6 mm for all the cases.

in the air gap. If the machine has a non-split magnetic system, the bolts securing the bearing cap and shell in the bearing housing are loosened. When a machine with two or more bearings is assembled, the labyrinth is removed from the largest of the bearings and a circular retainer is fitted in its place and secured to the bearing housing with all the bolts intended for fastening the labyrinth ring. The bearing carrying the retainer must carry a tag with the following inscription: "Important! Before mounting the motor, remove the retainer and replace it with a labyrinth ring!"

CHAPTER THREE

Acceptance and Storage of Electrical Machines in Store Houses

The electrical machines delivered from the manufacturing plant must be placed in permanent storage within at least five days from the moment of their arrival taking into account the sequence of their handing over for installation.

Prior to putting in storage, the machine must pass an acceptance procedure intended to check it for missing or damaged parts so as to take necessary measures for excluding the violation of installation terms. To this end, the machine is partially unpacked for examination and packed again if no damage is detected.

To prevent damage to the commutator, windings, and other parts, the machine and its components should be unpacked with particular care, in sheltered, dry, and clean premises inaccessible for unwanted persons. When machines or their components were kept before unpacking at low temperatures, they should be unpacked not earlier than a few days after their delivery to the unpacking premises so as to let them acquire the ambient temperature. This measure is necessary to prevent sweating of the parts (dew point), which may cause damage to the insulation.

The packing crate contains a parts'list, a duplicate of way bill, and a check tag which should be taken out as the crate is opened. The packing crate proper bears suitable markings indicating the consignee and consignor, the way bill No., as well as warning inscriptions, such as "THIS SIDE UP", "DO NOT TURN OVER", etc., which must be strictly observed. After having unpacked the machines, it will be necessary to check them for missing parts against the parts' list as well as for damage. In the action it is essential to examine the windings, iron stacks, commutators, slip

rings, shafts and other parts. In the event of damaged or missing parts a report shall be drawn out to place an order for the required parts. A damaged or insufficient anticorrosive coating is to be renewed.

The machined surfaces shall be cleaned of anticorrosive coating with the aid of kerosene. To facilitate this operation and to save waste materials, use can be made of bristle or wooden scrapers. Rough surfaces may be cleaned with brass scrapers. Steel scrapers are not recommended as they will damage the metal surfaces.

Varnish and paint coatings are to be removed by means of solvents, such as xylene, white alcohol. Small parts can be dipped in the solvent and held therein for 20 or 30 minutes. Large surfaces are to be amply moistened with the solvent and kept in this condition for 20 or 30 minutes whereupon the peeled-off paint is easily removed and the surface is wiped dry with a rag. When taking the machine out of storage, only the damaged varnish and paint coating is to be renewed. An anticorrosive coating in good condition is not to be removed if it does not interfere with the installation procedure. A particular care is to be given to parts for which high purity of surfaces and high accuracy of finish are essential.

Before cleaning the machines, measures shall be taken to prevent kerosene and dirt from getting on the windings, commutator, slip rings, and iron cores. The machined surfaces cleaned of dirt and anticorrosive coatings are to be wiped dry with clean rags and thoroughly inspected for damage. If serious defects, such as cracks, rust, deep burrs, scratches, etc., are detected an appropriate report shall be drawn out.

Particular attention shall be paid to the shaft journals of machines dispatched in a disassembled condition, as well as to the shaft extension surfaces receiving the half-couplings, to the flanges, half-couplings, shaft journals within the split bearing shells, commutators, brush gear, and slip rings.

The shaft journals and other parts shall be free from rust and scratches. The shaft journals of machines dispatched in a disassembled condition are to be thoroughly cleaned of all compounds and dirt with clean rags moistened in

gasoline. Wooden scrapers may be used for the purpose. Any other types of scrapers are not recommended as they can damage the ground surfaces.

The cleaned surfaces are to be wiped with a clean calico or gauze cloth moistened with ethyl alcohol and immediately after that coated with gun grease preheated to a temperature of 110-120°C. In the course of heating the grease shall not scum. If it does, the scum shall be removed and heating shall be proceeded till the grease stops scumming. The gun grease is to be applied in a solid layer of 1 or 2 mm without slips by means of a broad soft brush moved crosswise.

The shaft journal is then to be wrapped in a strip of wax paper, half the strip width overlapping, so that the strip side bearing upon the journal is not touched by hands. The paper is to be coated with hot grease and then the journal is covered with another layer of wax paper and with two layers of aluminium foil. The foil layer is covered with a layer of varnished fabric and wrapped in sackcloth overall. The sackcloth is to be double covered with varnish No. 26. The recess in the shaft support is to be coated with gun grease and an aluminium strip shall be placed therein. The shaft supports shall be arranged so that the journal is overhanging. It should be borne in mind that the shaft journals cannot be used as supporting surfaces.

The shaft extension surfaces to receive the half-couplings, as well as the flanges and the half-couplings (fitting surfaces) are to be flushed in gasoline and wiped dry with a calico or gauze cloth. The cleaned surfaces are to be coated with gun grease, wrapped in wax paper, then in fabric, and tied up. The wrapping is to be covered with varnished fabric, then with sackcloth and tied up again. The sackcloth is to be coated with varnish No. 26.

The shaft journals in the split bearing shells are to be flushed with gasoline, wiped dry with a calico or gauze cloth, and coated with gun grease.

The slip rings, stud threads, small items are to be flushed with gasoline, wiped dry with a clean calico cloth, coated with gun grease by means of a brush. Small items are to be placed on a net and dipped in hot grease. The greased parts are to be wrapped in wax paper.

The commutators and the brush gear are to be flushed with gasoline, thoroughly wiped dry, and wrapped in wax paper. The commutators are to be, in addition, wrapped in pressboard and tied up.

The bed plates, with the exception of the surfaces to be reinforced with concrete after installation, as well as the shaft extensions of small machines shall be flushed in gasoline, wiped dry, and double coated with varnish No. 26 by means of a brush or a sprayer. The first varnish coating shall be dried out for 5 or 6 hours at a temperature of 18-20°C and the second coating, for 24 hours at the same temperature.

All the above-mentioned parts, with the exception of commutators and brush gear, may be flushed in kerosene and then wiped with gasoline to remove water contained in kerosene.

The electrical machines shall be kept in store houses under conditions specified by Manufacturer's instructions so that, when handed over for installation, they were free from defects and did not require any additional repairs, finishing operations, cleaning, long-time drying, etc.

The electrical machines are to be stored in dry, clean, and ventilated premises protected against penetration of aggressive gases, coal dust, etc. The exposed metal surfaces of the machines shall be coated with anticorrosive grease and wrapped in a moisture-resistant material, such as wax paper. The temperature within the store room shall not be lower than 5°C.

Since the space in the machine rooms and on installation sites of factory shops is usually insufficient to accommodate all the machine parts to be installed, the latter are delivered from the store room to the installation site in an appropriate sequence. In the same sequence shall the parts be placed in the store room so as to facilitate their handling.

CHAPTER FOUR

Requirements to Installation Premises and Foundations

All construction and finishing jobs in premises meant for the machines shall be fully completed before the installation of the machines. The premises must be large enough to afford space for the installation and dismounting of the machines (pulling out the rotor in the axial direction, accommodating the machine parts, giving an easy access to the machine for its attendance, etc.).

The ceilings over the basements accommodating the equipment shall be provided with hatches suitable for passing large parts of electrical machines and handling equipment. The cable conduit trenches shall be cleaned and dried out. Openings must be provided to pass assembled machines or their large components.

The premises shall be equipped with overhead travelling cranes or jibs of sufficient load-carrving capacity for handling assembled machines or their heavy parts. The height of the premises shall allow an assembled machine or its large component to be easily carried over other machines mounted therein with the overhead crane hook being in the extreme upper position.

During installation, the temperature in the machine rooms and basements shall not be lower than 5°C. The machines shall never be mounted in dusty premises.

The medium-size and large electrical machines are to be mounted on foundations which shall be used as their baseplates intended to transmit to the ground the static (mass) load and the dynamic load of the running machine. The foundation shall be of a sufficiently robust construction to take the static and dynamic loads so as to prevent displacement and vibration of a running machine.

Foundations are usually made of concrete or ferroconcrete. In order to avoid unequal setting, misalignment of bed plates, and incorrect mounting of the machines, the motors and the driven mechanisms or prime movers are to be erected on a common foundation irrespective of whether the machines incorporated in a set are meant for installation on a common bed plate or on separate plates.

Foundations for medium-size and large machines shall be separated from columns and other supporting structures of the building so as to prevent them from taking vibrations due to an unbalance of the machine parts or due to jolts transmitted from associated machines. For the same reason, the electrical machine foundation shall never be used as a supporting structure for any parts of the building or for other machines which are not incorporated in the particular set.

The electrical machine foundations shall be made in full compliance with the design requirements and, when accepted for installation, they shall be free from cavities, pits, surface cracks, chipped corners, and naked fittings.

The foundations shall be cleaned of falsework and plastered or rubbed over, plugs shall be removed from holes, pits, cavities and built-up concrete shall be removed.

Before handing over the foundation, the pockets shall be filled back; foundations handed over for the installation of medium-size and large electrical machines shall bear main centre lines marked out by the Builders. The main centre lines shall be indented on metal strips measuring 80 × 80 mm embedded in the foundation body.

The foundation upper surface mark relative to the zero reference point shall be attached to bench marks embedded in the foundation body. Bolts or metal rods shall be used as bench marks.

Basic dimensions of the foundation are specified by the electrical machine Manufacturer. The foundation must be provided with holes to receive anchor bolts securing the bed plates. The holes shall have open recesses (Fig. 4.1) which are formed by detachable core plugs placed in concrete while the foundation is made. Holes shall not be made in a foundation after the latter is ready. After the machine is installed, the holes and anchor bolts shall be grouted in cement.

A new method has been recently put in practice in ferrous metallurgy plants. Anchor bolts are fitted in foundations beforehand.

For fitting anchor bolts of 30-35 mm in diameter it is good practice to use a jig with bolts (Fig. 4.2) secured on the wooden falsework of the foundation proper. Such a jig provides for high accuracy fitting of bolts and makes it unnecessary to correct or alter the holes, which is the case with foundations constructed by usual methods.

A new method of the construction of foundations for electrical machenes has been used since 1970. This method consists in the following.

Before the concrete has hardened and just after the last portion of concrete is poured, wooden blocks (templates), 25-30 mm thick, are set on the bearing surfaces at places where pads and shims are to be installed (Fig. 4.3). The templates shall be 80-100 mm greater in size than the pads and shims, the size of the latter being determined by the mounting dimensions of the bed plates. After the concrete has hardened, the templates are removed, and seats formed underneath do not require additional rubbing-over or cleaning-off.

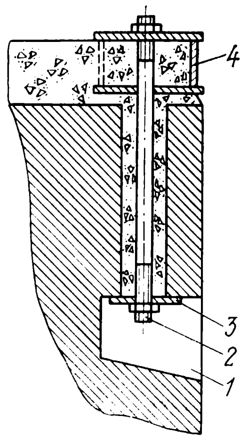


Fig. 4.1. Recess in the foundation to receive anchor bolt plate

1 — recess; 2 — anchor bolt; 3 — anchor plate; 4 — bed plate

This method was first used by two metallurgical plants for the foundations of electrical machines driving a rolling mill and a continuous billet mill with the result that a considerable saving was gained in labour consumed in setting and levelling the bed plates.

Wooden templates are to be made and fitted in appropriate places by builders under the supervision of electricians.

The electricians are to obtain reference drawings of bed plates specifying all the fitting dimensions and showing the arrangement of stiffening ribs before making the foundations ready for the installation of electrical machines.

The machine rooms and foundations for large electrical machines are to be accepted according to reports, the dimensions of premises and foundations being checked from the point of view of building jobs made and the condition of installation site to receive the electrical machines. To-

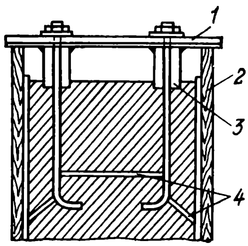


Fig. 4.2. Installation of anchor bolts by means of a jig

1 — jig; 2 — wooden falsework; 3 — metal entrenching tool; 4 — distance bars

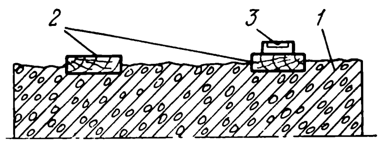


Fig. 4.3. Setting wooden blocks (templates) on bearing surfaces of foundations at points of installation of pads and shims

1 — foundation; 2 — wooden block (template); 3 — level

lerances and deviations from design dimensions shall be in full compliance with appropriate sections of the "Building Standards and Regulations".

The quality of the foundation is essential not only for the electrical machines and driven mechanisms but also for the machine houses and adjacent buildings.

The detrimental effect of oil, which gradually disintegrates concrete, is eliminated by covering the concrete foundation with appropriate oil-resistant paint or water-soluble glass.

CHAPTER FIVE

Electrical Machine Hoisting and Haulage Equipment

During installation the electrical machines and their parts shall be handled, first of all, by hoisting and haulage equipment provided in the machine rooms according to the design and meant for the installation of electrical machines as well as for their further maintenance and repairs. In the process, use can be made of a combination of overhead and floor-mounted transport facilities, freight lifts in multistory machine houses where the floor height difference is more than 10-15 m, as well as the shop overhead travelling cranes.

All the necessary handling facilities and a sufficiently large space shall be provided for machines delivered in an assembled condition on their way to the installation site. Manual labour shall be avoided in handling heavy items. Such jobs shall be carried out with the aid of overhead and jib cranes, monorails with trolley hoists or tackle blocks, rail transport, automobile, tractor, and railway cranes, autotrailers, hand winches, electric hoists, tackle and compound blocks, jacks, loading booms, as well as other hoisting and slinging facilities, devices, and tools.

Ropes, Slings, and Slinging Arrangements

Ropes (Fig. 5.1) are used for the attachment of heavy items to the hooks of hoist mechanisms and for fastening the items to facilitate their handling; they are likewise employed as load lifting ropes in miscellaneous hoist mechanisms, as boom, stay, conveying, and pulling ropes.

Tying ropes (fastening cords) are those knotted at the ends. Fig. 5.2 illustrates the widely used methods of fastening the slings to hooks, as well as knotting and terminating the ends of fastening cords.

The most popular are hemp and steel-wire ropes. Cotton and capron ropes are used less frequently.

The *hemp* ropes are made of tarred hemp (tarred ropes) or of white hemp yarn (white ropes). The tarred ropes are resistant to moisture, but they are heavier than, and not so strong as, the white ropes. It is common practice to use white

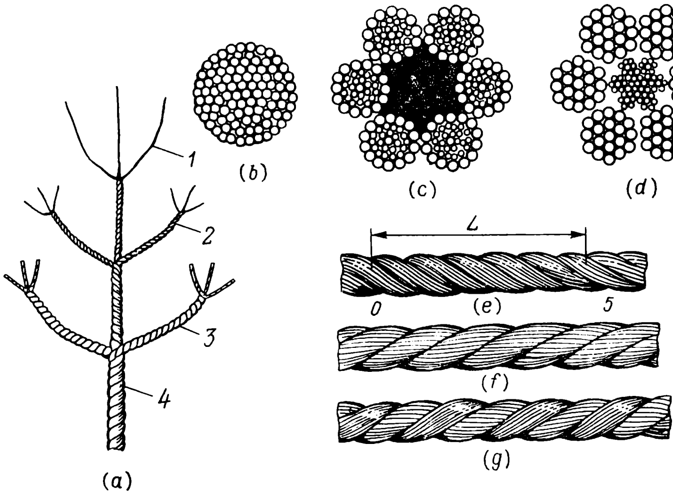


Fig. 5.1. Ropes

(*a*) hemp, cotton, capron ropes; (*b*) stiff single-lay ropes; (*c*) double-lay rope, type ЛК-РО, compound-laid, fibre-core; (*d*) double-lay rope type ЛК-Р, metal-core; (*e*) unidirectional-laid rope; (*f*) regular-laid rope; (*g*) compound-laid rope; *1* — hemp yarn; *2* — strand; *3* — cord-laid rope; *4* — cable rope; *L* — lay (for six-strand rope); 0 — zero mark showing the rope lay beginning; *5* — end lay mark (for six-strand rope)

ropes of 9.6 to 28.7 mm in diameter in mounting the electrical machines. Hemp ropes are lighter and more flexible than steel-wire ropes, which makes them more suitable for tying in knots. They are employed in pulley blocks for manually hoisting the machine parts, as span ropes in hoisting the loads as well as for slinging items having machined corners and surfaces. The hemp ropes are usually meant for slinging items weighing up to 200 kg as heavier items will require fastening cords of too large a diameter which will make them inconvenient in operation. The loop at the end

of the hemp rope shall be dressed with a thimble (see Fig. 5.4*e*, *g*).

Along with hemp ropes, use is made of *cotton* ropes, fibre and synthetic (capron) ropes. *Capron* ropes are available

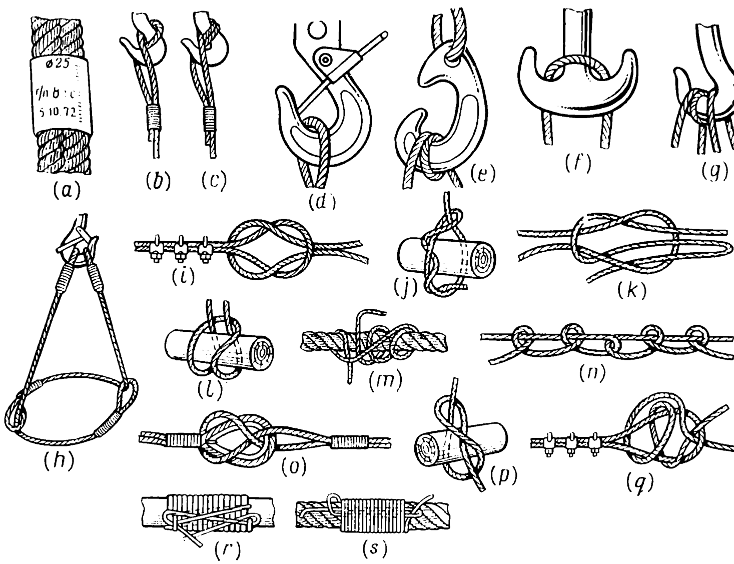


Fig. 5.2. Fastening the slings to hooks, knotting and terminating the ends of fastening cords

(*a*) tag (grade) of sling; (*b*) cat's paw knot; (c) cat's paw knot with overlap; (*d*) loop sling; (*e*) ring or loop sling with overlap; (*f*) ring or loop sling; (*g*) two ring or loop slings (one with overlap); (*h*) slinging by loop; (*i*) right knot; (*j*) jamming knot; (*k*) reef knot; (*l*) dead loop; (*m*) mooring knot; (*n*) water knot; (*o*) thimble or loop tying; (*p*) figure-eight knot; (*q*) mesh knot; (*r*) turn termination; (*s*) plain termination

of high grade and normal grade and have a diameter of 7.9 to 63.7 mm. The breaking load of a high-grade capron rope is 1180 to 58,990 kg and that of a normal-grade capron rope is 1010 to 50,850 kg, respectively.

The cord-laid hemp, cotton, and capron ropes are composed of three strands. The latter are twisted of separate yarns. A few cord-laid ropes *3* are twisted to obtain a thick and flexible cable rope *4* (see Fig. 5.1*a*). Strands are laid in a

direction opposite to that of yarns. The cord-laid rope is twisted in a direction opposite to that of the lay of the strands but in the same direction as the yarn lay (see Fig. 5.1*a*). Capron yarns are twisted of complex threads.

The size of fibre and capron ropes is determined by the circumference around their sectional area or by the rope diameter.

The *steel-wire* ropes are employed for slinging items having mass over 200 kg, for hoist mechanisms, span ropes, stay ropes, etc.

The most frequently used in installation are round-section ropes of the following types: type TK double-lay ropes (cables) with point crossing of separate wires between the strand layers; type ЛК ropes with line crossing of wires (wires in strands are crossing along their entire length and not at separate points), and type ТЛК ropes with point-line crossing of wires. The *double-lay* ropes, as distinct from the single-lay ones, are made up of strands. The *single-lay* ropes are twisted of separate wires (Fig. 5.1*b*). The single-lay ropes are too stiff to be used in installation.

The double-lay ropes are available of a *regular-laid* type in which wires are stranded in one direction and the strands are twisted in a different direction (Fig. 5.1*f*); *unidirectional-laid* type when wires are stranded and the strands are twisted unidirectionally (Fig. 5.1*e*); *compound-laid* type in which adjacent strands are laid in different directions (Fig. 5.1*g*). The double-lay ropes may be fitted with a fibre or metal *core* (Fig. 5.1*c*, *d*). The type ЛК-РО *compound rope* is one of alternates of the double-lay ropes. This rope has its separate strands made of different-diameter wires (Fig. 5.1*c*).

The ropes are manufactured (and designated): (a) according to their application, passenger-and-freight (ГЛ), freight (Г); (b) according to mechanical properties of wire, high-grade (В), 1st grade (I), 2nd grade (II); (c) according to the wire coating, clear wire, zink-plated wire for light-duty (ЛС), medium-duty (СС), and heavy-duty (ЖС) conditions; (d) according to the direction of lay, right-handed (П), left-handed (Л); (e) according to the lay of the rope components, regular-laid, unidirectional-laid (О); (f) according to the method of laying, untwisting (Р), non-untwisting (Н); (g)

according to the degree of spinning, heavily spinning, slightly spinning (МК).

Each type of rope has its advantages and disadvantages which shall be taken into account in selecting the optimum version. Regular-laid ropes, for instance, are less flexible than unidirectional-laid ropes, but they are not liable to untwisting; a fibre core makes the rope flexible and resistant to impact loads with added ability of absorbing and preserving the lubricant, but reduces its mechanical strength; a compound rope has a high space factor, good flexibility and long service life, but is much more complicated and expensive to manufacture; the rope is the more flexible, the thinner are its wires, but the latter is more expensive and rapidly wears out, etc.

The rope is to be selected depending on its purpose. So, slings and fastening cords subject to sharp bends in slinging miscellaneous loads shall be made of extra soft ropes, such as type ТК six-strand ones having 61 wires per strand; load-lifting ropes are to be soft, such as type ТК or ТЛК, made up of six strands, 37 wires per strand, or type ЛК organic-core, six-strand, 36 wires per strand; wire braces which are not subject to sharp bends, shall be made of comparatively stiff ropes, such as six-strand ropes having 19 wires per strand, etc.

Prior to use in a hoist, slinging or fastening to items being handled, the steel-wire, hemp, cotton, and capron ropes shall be checked for mechanical strength calculated from the following formula:

$$\frac{P}{S} \geqslant K \qquad (5.1)$$

where K = factor of safety

P = rated breaking stress of the entire rope specified by a certificate or standard, kg

S = maximum tension on rope leg (rope pull) less dynamic stress, kg

The factor of safety, K, for hemp, cotton, and capron ropes shall be at least 8.

The minimum permissible factor of safety, K, for steel-wire ropes is as follows:

(a) for slings and fastening cords tied to the loads or attached to them through hooks, thimbles, shackles—6;

(b) for sling and stay ropes (braces)—3.5;

(c) for load-lifting and crane ropes of hand-operated hoists—4; for those of motor-driven hoists operating in a light duty—5; for those of motor-driven hoists running

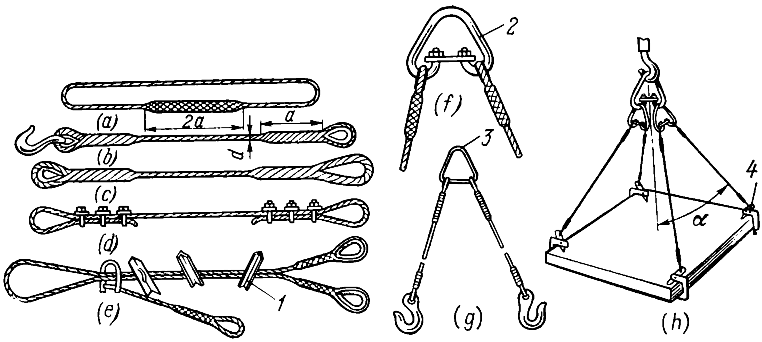


Fig. 5.3. Steel-wire rope slings

(*a*) multipurpose (circular); (*b*), (*c*), (*d*) light-weight (loop) single slings; (*e*) semiautomatic slings; (*f*) (*g*) two-leg slings; (*h*) four-leg slings; *1* — stock spacers; *2* — split hanger; *3* — welded hanger; *4* — lever-type gripper

in a heavy duty—6; for the same ropes of motor-driven hoists operating in a moderate duty—5.5.

When the rope certificate or test report specifies only the total rated breaking stress of all the rope wires, the P value is determined by multiplying the total breaking stress of the wires by 0.83.

In calculating the rope slings with due account for the number of rope legs and their angle of inclination to the vertical plane (Fig. 5.3*h*), the tension of each leg is to be found from the equation:

$$S = \frac{1}{\cos\alpha}\,\frac{Q}{n} = m\,\frac{Q}{n} \qquad (5.2)$$

where Q = mass of the load suspended from sling hook, kg
n = number of legs
α = angle of inclination of legs to the vertical plane
m = $1/\cos\alpha$ factor (at α equal to 0,30, 45, 60°, m will be, respectively, 1, 1.15, 1.42, 2)

The permissible load for the rope in kilograms is to be found from the equation below taking into consideration formulas (5.1) and (5.2):

$$Q = \frac{Pn}{Km} \tag{5.3}$$

In selecting ropes for slings according to the calculated stress per rope it shall be borne in mind that the rope diameter is not to exceed 40 mm as slings made of ropes having a larger diameter are inconvenient to use.

Since there is a great variety of ropes as to their construction, purpose, application, and operating conditions, the permissible stresses for the ropes of different constructions and diameters are not specified by the standards, and if given in reference tables, the specified operating conditions of the ropes are mentioned too.

For instance, Table 5.1 specifies permissible stresses for fastening white hemp ropes at a safety factor $K = 8$.

For the sake of comparison, Table 5.2 gives permissible stresses for some double-lay ropes, types ЛК-РО and ТЛК-РО, approximately equal in size and used in hand-operated winches at a safety factor $K = 4$ and for double-lay ropes employed in a two-leg sling at $K = 6$, each leg inclined to the vertical at $\alpha = 60°$.

Ropes checked for mechanical strength as specified above and installed on a hoist or used for making a sling shall pass, in addition, appropriate tests. The ropes shall not be admitted for use unless they are furnished with test certificates.

Every steel-wire rope is supplied by the Manufacturer complete with a certificate specifying its construction and factory test results, including its actual breaking stress. The rope shall bear a tag indicating its diameter and breaking stress.

Slings are, essentially, suitably connected lengths of ropes or chains fitted with special hangers for rapid, convenient, and safe fastening of loads.

The steel-wire rope slings (Fig. 5.3) are available of miscellaneous forms.

The single-leg stock slings illustrated in Fig. 5.3*a*, *b*, *c*, *d*, *e* are made of the following types: multipurpose (circular)

Table 5.1

Permissible Stresses for Fastening White Hemp Ropes (USSR State Standard, GOST, 483-55)

Rope dia., mm	Permissible stress, kg								
	load suspended from one end of rope	load suspended from two legs				load suspended from four legs			
		angle α between leg and vertical plane (Fig. 5.3h)				angle α between leg and vertical plane (Fig. 5.3h)			
		0°	30°	45°	60°	0°	30°	45°	60°
11.1	85	170	150	120	85	340	300	240	170
12.7	110	220	190	155	110	440	380	310	220
14.3	140	280	245	195	140	560	490	390	280
15.9	165	330	285	230	165	660	570	460	330
19.1	230	460	400	325	230	920	800	650	460
20.7	265	530	460	375	265	1060	920	750	530
23.9	355	710	610	500	355	1420	1220	1000	710
28.7	485	970	840	680	485	1940	1680	1360	970

Table 5.2

Permissible Stresses for Some Double-Lay Steel-Wire Ropes (USSR State Standards, GOST's, 7668-69 and 7669-69)

Type ЛК-РО6×36 (1+7+7/7+14)+1 f.c.*			Type ТЛК-РО6×36 (1+7+7/7+14)+7×7(1+6)		
Rope dia., mm	permissible stress, kg		Rope dia., mm	permissible stress, kg	
	for hand-operated winch	α = 60° for two-leg slings		for hand-operated winch	α = 60° for two-leg slings
15	3450	2300	14.5	3180	2120
16.5	4125	2750	16	3890	2590
20	5300	3530	19.5	5630	3750
25.5	8125	5420	25	8050	5370
33	13,220	8820	32.5	13,600	9100
36.5	17,690	11,790	36.5	18,200	12,120

* f.c.— fibre core.

intertwined or clamped; light-weight (loop) single slings looped at the ends and terminating into one or two thimbles, or without thimbles, or with a hook on one end; semiautomatic slings. The slings can be terminated by intertwining (Fig. 5.4*a*), by means of different types of clamps (Fig. 5.6), or by a socket-and-wedge joint (Fig. 5.4*e*). The intertwined portion *a* (Fig. 5.3*b*) in multi-purpose slings

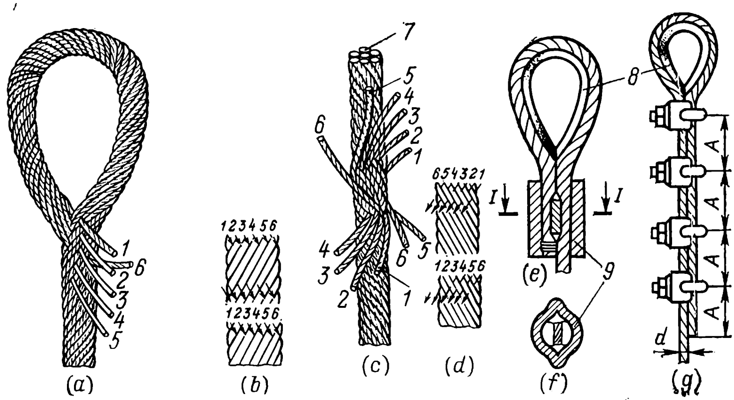


Fig. 5.4. Rope (sling) termination and splicing

(*a*) intertwining of a loop sling; (*b*) sequence of intertwining; (*c*) rope (sling) splicing; (*d*) intertwining sequence diagram; (*e*) eyelet termination with a wedge-and-socket joint; (*f*) *I-I* section; (*g*) eyelet termination with clamps; *1-6* — numbering of running strands; *7* — rope core; *8* — eyelet; *9* — clamp

shall measure at least 40 diameters of the rope and that in loop slings, at least 20 diameters. The number of clamps shall be from three to six, distance *A* (Fig. 5.4*g*) between the clamps as well as between the last clamp and the rope end measuring at least six rope diameters ($A \geqslant 6d_r$). Semiautomatic slings (Fig. 5.3*e*) have two thimbles fitted on both ends of the rope and a loop formed by the rope, or they may have a single thimble fitted on one end of the rope and a loop made by the rope proper on the other end. The rope is intertwined at the ends. A yoke and stock spacers are placed on the sling.

The loop of the semiautomatic sling is slipped on the hook of a hoist, tied around the load to be lifted and the thimble-terminating ends of the rope are inserted into the

yoke. The spacers are placed on the acute-angled corners of the load before tensioning the rope. To remove the sling from the load, the yoke pin shall be separated from the rope by means of a trigger cable.

The technical characteristics of the single-leg stock slings vary within a wide range, *viz.*, their load-lifting capacity may be from 0.25 to 25 t, their length is between 0.63 and 10 m, the rope diameter is from 6.1 to 60.5 mm, the mass is from 0.4 to 339 kg.

The two-leg stock slings (Fig. 5.3*f*, *g*) are available with a split (Fig. 5.3*f*) or welded (Fig. 5.3*g*) hanger, with intertwined thimbles on the two ends of each leg, with fastening hooks on the bottom thimbles. Their load-lifting capacity is between 1 and 25 t, the length is from 1.6 to 10 m, the mass is from 10 to 732 kg.

The four-leg stock slings (Fig. 5.3*h*) are available with one or three split hangers with interlaced thimbles and may have fastening hooks. Their load-lifting capacity may be from 1 to 10 t, the length varying from 2.5 to 6.3 m and the mass being from 8 to 238 kg.

Miscellaneous modifications of steel-wire rope slings can be made, such as those with special carrying hooks for slinging steel sheets and bed plates as well as many other special-purpose slings. Fig. 5.2*b*, *c*, *d*, *e*, *f*, *g*, *h* illustrates methods of fastening the slings to hooks.

Hemp, cotton, and capron slings are used for lifting small parts of electrical machines having finished surfaces as well as for items having a mass not over 200 kg. Slinging is made by tying the ropes around the load as shown in Fig. 5.2.

Rope Termination and Splicing (Fig. 5.4)

The loop at the end of a steel-wire or hemp rope attached to a hoist as well as the loop of a sling fastened to thimbles or hooks and other parts shall be terminated as follows: with the free end of the rope being intertwined; with clips fitted on steel-wire ropes; or with the aid of a socket-and-wedge joint (Fig. 5.4*a*, *e*, *g*).

In order to prevent untwining of strands in fastening ropes, the ends of the ropes shall be terminated with a soft wire wound either by a plain or an S-turn method (see

Fig. 5.2*r*, *s*). Before trimming, the ropes shall be likewise terminated over a length measuring at least five rope diameters.

After a sling is made, it shall be fitted with a tag (or label) interlaced with one of the rope strands. After the sling has passed an appropriate test, its diameter, length, load-carrying capacity, and the date of the next test shall be stamped on the tag (see Fig. 5.2*a*).

Discarding and Lubrication of Ropes

The steel-wire ropes being in use shall be discarded in compliance with standards specified in Table 5.3 according to the number of broken wires on a length equal to one lay (Fig. 5.1*e*).

Table 5.3

Discarding Standards for Regular-Lay Load-Lifting Ropes According to the Number of Broken Wires per Lay

Rope safety factor	Number of broken wires per lay indicating critical condition of rope		
	6×19=114 wires plus 1 fibre core	6×37=222 wires plus 1 fibre core	6×61=366 wires plus 1 fibre core
Up to 6	12	22	36
6-7	14	26	38
Over 7	16	30	40

For other types of ropes not indicated in the table the critical condition shall be determined by the number of broken wires per lay of the rope having approximately the same number of strands and wires. If a load is suspended from two ropes, each one is to be rejected separately. In case a broken strand is detected, the rope shall be rejected and sent for repair.

Fastening cords and slings shall be subjected to technical inspection after manufacture and each time after repairs (see Table 2.1).

The steel-wire ropes shall be protected against corrosion by lubricants, the lubrication intervals being: at least once every two months for load-lifting and pulley block ropes; at least once every 1.5 months for fastening cords and slings; at least once every three months for bracing wires, and at least once every six months for ropes kept in storage. For lubrication use shall be made of rope grease

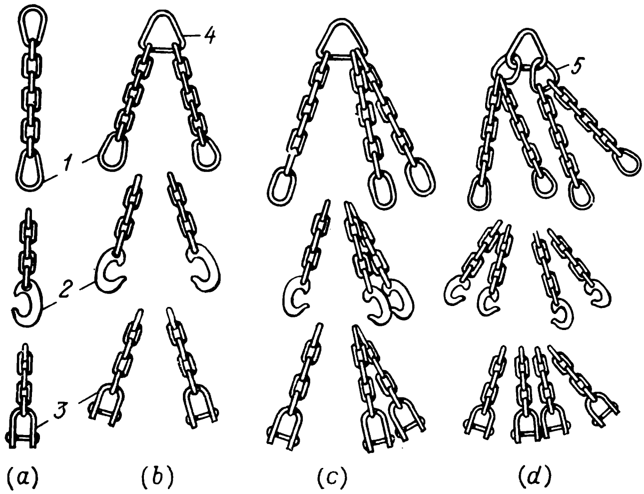


Fig. 5.5. Slings of noncalibrated fabricated chains
(*a*) single-leg; (*b*) two-leg; (*c*) three-leg; (*d*) four-leg; *1* — ovoid end link; *2* — hook; *3* — yoke; *4* — end shackle; *5* — intermediate shackle

grades I, II, and III according to the Manufacturer's instructions.

Slings made of non-calibrated fabricated chains (Fig. 5.5) used in installation are available of four types, *viz.* single-leg, two-leg, three-leg, and four-leg slings. Each type includes several type varieties.

The single-leg chain slings are manufactured of three type varieties, namely, slings with ovoid end links on both sides; slings with an ovoid end link *1* on one side and a hook *2* or a yoke *3* on the other (Fig. 5.5*a*).

The two-leg, three-leg, and four-leg slings are made up of three type varieties of chains, *viz.* they can be terminated

on the side of the crane hook suspension with one or three links suspended from shackles *4* and *5* while on the other end the sling legs may be dressed with an ovoid end link *1*, a hook *2*, or a yoke *3* (Fig. 5.5*b*, *c*, *d*).

The load-lifting capacity of the chain slings is from 0.4 to 32 t and their length is from 0.8 to 8 m. The condition inspection standards for the chain slings are similar to those for the steel-wire slings. In selecting the slings and testing

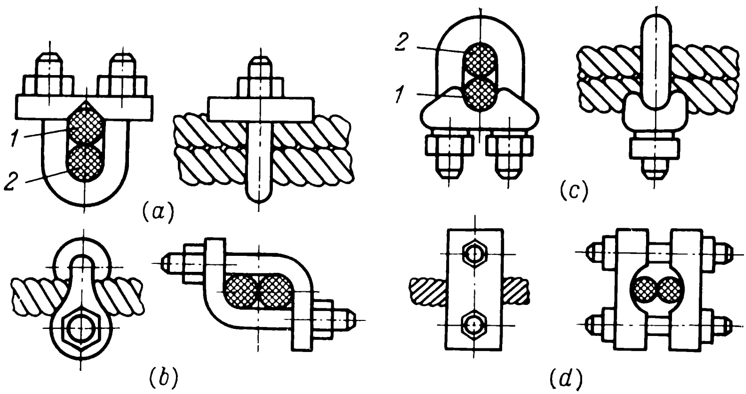


Fig. 5.6. Clamps

(*a*) with cramp and strap; (*b*) with clips; (*c*) with block; (*d*) with straps; *1* — long leg; *2* — short leg

them for strength the same equations are used as in the case of steel-wire ropes, the safety factor, K, for the fabricated chains being equal to, or higher than 5.

The slings are furnished with the following accessories:

Thimbles for ropes having a diameter of 3.6 to 75.5 mm (Fig. 5.4*e*, *g*);

Clamps (Fig. 5.6): with a block for ropes of 5 to 62 mm in diameter; with a cramp and a strap for ropes of 8.7 to 33.5 mm in diameter; with clips for ropes of 8.7 to 33.5 mm in diameter; with two straps for ropes of 3 to 22 mm in diameter. Clamps with two straps may flatten the rope, therefore they are rarely used. When fitting the clamps, it shall be borne in mind that the short leg must be on the U-shaped end of the cramp;

Socket-and-wedge joint (Fig. 5.4*e*, *f*) for ropes having a diameter of 3 to 22 mm;

Hooks (Fig. 5.2): of 0.4 to 5 t lifting capacity (Fig. 5.2*e*); fastening with knot joint, of 0.25 to 25 t lifting capacity; spring-type, of 0.4 to 8 t lifting capacity; with gravity lock, of 0.4 to 100 t lifting capacity;

Yokes of 0.1 to 37 t lifting capacity (Fig. 5.5 *a*);

Hangers: split, of 0.4 to 10 t lifting capacity (Fig. 5.3*f*); fabricated, of 10 to 32 t capacity (Fig. 5.3*g*); three-link oval-shaped, of 0.4 to 10 t capacity;

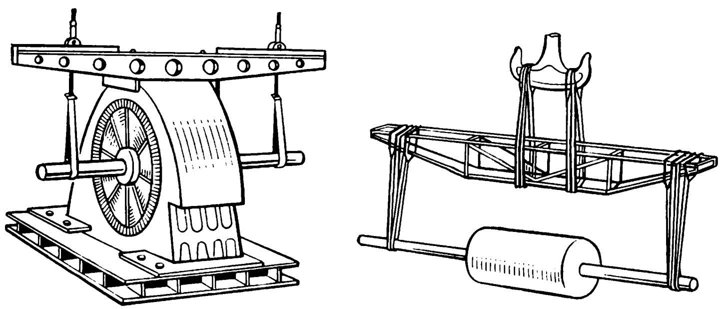
Links: triangular intermediate (shackles), of 0.4 to 32 t lifting capacity (Fig. 5.5*d*); ovoid end and intermediate, of 0.4 to 25 t lifting capacity (Fig. 5.5*a*);

Stock gaskets used to prevent damage to the slings when bent at sharp edges of items being handled (Fig. 5.3*e*);

Grippers: universal; eccentric; self-clipping; lever-type for sheets and plates of up to 60 mm in thickness (Fig. 5.3*h*), etc.

Slinging Arrangements

Lifting beams (Fig. 5.7): special-purpose beams for driving the rotors of large machines into the stators, rollers being



(*a*) (*b*)

Fig. 5.7. Lifting beams

(*a*) special-purpose lifting beam for driving rotor into stator; (*b*) special-purpose lifting beam for handling armatures, rotors, and other long pieces

provided for moving the load along the beam (Fig. 5.7*a*); special-purpose beam for handling the armatures and rotors of machines as well as long pieces; the lifting capacity of

these beams is from 80 to 100 t (Fig. 5.7*b*); lifting beams made up of a pipe and stops and intended for handling small motor-generator sets (Fig. 9.1); miscellaneous lifting beams having a length of 2.36 to 7.7 m, a mass of 78.7 to 773.9 kg and a load lifting capacity of 10 to 100 t. These beams are used for handling long pieces of machines and sets. Special lifting beams for handling electrical machines and their parts are not produced by our industry and shall be designed and manufactured by the installation enterprises each time such a facility is required.

Distance pieces protecting the rotor, armature, and stator windings against injury from slings are made of wooden bars, sleepers, or metal pipes.

Sling shackle (Fig. 5.8) is suitable for lifting the machine parts in which the centre of gravity may be located at any point. The sling shackle consists of the shackle proper, two side plates welded with two forks, a body, three pins, a lifting beam with two clamps, and a sling. When idle, the sling is free to slide along the slots in the body. When a force of 100 kgf is applied to one of the sling legs, the clamps press the sling to the body and hold the latter in position. The lifting capacity of the sling shackle is 3 t, its mass is 15 kg.

Pulleys, compound blocks, tackle blocks, trolley hoists are shown in Fig. 5.9.

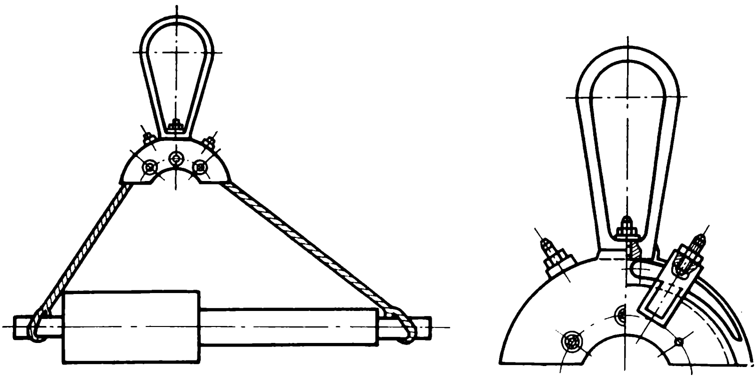
Pulleys (Fig. 5.9*a*) meant to change the direction of the rope and the force applied are referred to as *angle pulleys* or *snatch blocks*, those intended to reduce the force required for lifting a load are termed as *load blocks* or *pulley blocks.*

Pulleys are available with hemp and steel-wire ropes as well as with chains. Snatch blocks are fixed in position and have a single wheel to receive the rope. These are single-wheel pulleys. Multi-wheel pulley blocks may have from two to six wheels. The pulleys may have a single-horn hook (provided with a turnbuckle) or a double-horn hook (Fig. 5.2*f*, *g*), with an eyelet or a cramp, as well as special-purpose pulleys, such as those with an eyelet and a swivel or a pulley used as a snatch block only. The eyelet pulleys are most often used as an upper pulley of a compound block. To facilitate the rope passage at any desired place without pulling it through, the single-wheel snatch blocks are fitted with one or two flapping side plates or with two flap clevi-

ses. Tables 5.4 and 5.5 specify characteristics of pulleys used in electrical machine installation.

The angle pulley diameter shall measure at least ten diameters of the rope. Cast-iron wheels are employed for hemp rope pulleys.

The wheel groove shall have a diameter exceeding that of the rope by 1-3 mm. The wheel-to-rope diameter ratio



(*a*) (*b*)

Fig. 5.8. Sling shackle
(*a*) in working position; (*b*) sectional view

for steel-wire ropes of pulley blocks shall be at least 16 and that for snatch blocks, at least 12.5.

The chain wheels in chain pulleys are called sprockets and have grooves along their rim to fit the dimensions of the chain link. The sprocket diameter shall be (a) at least 20-fold as large as that of the chain iron for hand-operated mechanisms and (b) at least 30-fold as large for power-operated mechanisms. Sprockets are employed in tackle blocks, motor hoists, and other mechanisms.

Compound blocks (Fig. 5.9*b*) are load-lifting mechanisms built up of two pulleys joined together with a rope which is wound in turn over all the wheels of each pulley.

Such a construction provides for a lower tension of the rope directed towards the hoist (gain in force), but in this case a longer rope is to be wound on the drum (penalty in distance, time, and speed). In an assembled compound

Table 5.4

Single-Wheel Pulleys with Hemp Ropes

Pulley load-lifting capacity	Dimensions, mm			Pulley wheel diameter, mm	Mass, kg	Rope diameter, mm
	height	width	thickness			
100	340	126	65	90	2.5	14.3
250	425	165	85	116	4.9	18.1
500	560	240	105	170	11.6	28.7

Table 5.5

Angle Pulleys and Load Blocks with Steel-Wire Ropes

Pulley description	Load-lifting capacity, t	Number of wheels	Wire diameter, mm	Mass, kg
With hook	1-50	1-5	7.4-28.5	3.6-760
With double-horn hook	30-50	4-6	26-28.5	613-1005
With hook and flap clevises	1.25-10	1	8-23	6.7-92.8
With eyelet	1-100	1-5	7.4-32.5	3.1-1760
With eyelet and flap side plates	1.25-10	1	8-23	5.5-49
With eyelet and swivel	20	1	—	—
With cramp	10-100	1-5	21.5-28.5	95-1605
Special snatch block	25	1	32.5	167

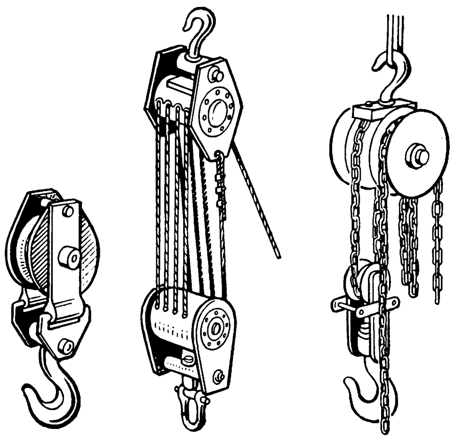
block the rope is attached on one end to the eye of one pulley, then it is passed in turn over the wheels of both pulleys and its other end running from one of the pulleys is wound on the hoist drum. The rope end wound on the hoist drum is practically always running from the fixed pulley which makes it unnecessary to use an additional angle pulley.

In assembling compound blocks the following shall be borne in mind:

in the case of an even number of cords or wheels incorporated in the compound block, the rope end shall be tied to the fixed pulley;

in the case of an odd number of cords, the rope end shall be secured to the movable pulley.

Compound blocks used for handling electrical machines comprise from 2 to 12 cords to handle loads having a mass of 1 to 50 t or, less frequently, up to 100 t.



(a) (b) (c)

Fig. 5.9. Pulleys, compound blocks, and tackle blocks
(*a*) pulley; (*b*) compound block; (*c*) tackle block

A minimum permissible distance between the fixed and movable pulleys is specified for every compound block. For pulleys with hooks this distance shall be 500 mm and for those with shackles, 350 mm.

Tackle blocks (Fig. 5.9*c*) are, essentially, hoist mechanisms consisting of a chain block operated by an endless driving chain or a lever-type ratchet gear drive. Worm and geared tackle blocks of 1 to 3 t lifting capacity as well as lever-operated tugger gear tackle blocks of 0.5 to 1.5 t capacity have found most wide application.

The driving member of worm and gear tackle blocks is a fabricated calibrated chain. All the tackle blocks are

furnished with a reliable automatic brake (screw type in most cases). Tackle blocks of different constructions are designed to carry loads over a height of up to 3 m. Upon request, they may be designed to carry loads over a height of up to 12 m. The load-lifting capacity of worm tackle blocks is from 1 to 12.5 t and that of gear tackle blocks is from 0.25 to 8 t.

Trolley hoists are, essentially, tackle blocks furnished with a motor-driven load-lifting and trolley-moving gear. The trolley travels horizontally over a monorail. Current is supplied to the hoist via trolleys or a flexible cable. The trolley hoists are available with a load-lifting capacity as high as 10 t.

Winches and hoists are used for horizontal, vertical, and inclined haulage of electrical machines and their parts, as well as other loads.

Hand winches, as well as mechanical and electrical hoists, are available along with unitized hoists. The steel-wire ropes used for winches and hoists are 200 to 300 m long, their diameter being selected depending on the mass of permissible load. The hoists shall be mounted so that the driving end of the rope be underwinding the drum.

The hand winch is set in motion by turning the grips on both ends of the drum (in case of geared winches) or by rocking the lever (in case of lever-type winches), the force being applied manually.

The hand-operated tugger winches have a load-lifting capacity (tractive force) of 0.5, 0.25 and 1 t at a rope diameter of 5, 7.5 and 11 mm, a rope length of 35 m and a mass of 6.5, 27.1 and 33.2 kg, respectively.

The hand winches set in motion by handle grips have a load-lifting capacity of 0.5 to 5 t at a rope diameter of 8.8 to 21.5 mm, a rope length of 75 to 110 m, and a mass of 200 to 1506 kg.

The hand winches operated by a lever have a load-lifting capacity of 0.75, 1.5 and 3 t at a rope diameter of 7.5, 12, and 16.5 mm, a rope length of 20, 20 and 15 m, and a mass of 17, 34 and 54.5 kg, respectively. The lever-operated hand winches are also available of 5-t capacity.

The electric hoists are operated by a reversible drive supplied with power from 380/220-V ac mains. Their load-lif-

ting capacity is from 0.125 to 12.5 t at a rope diameter of 4.8 to 33 mm, a rope length of 60 to 800 m and a mass of 34 to 5644 kg.

The unitized hoists are operated both electrically and manually. The most widely used of these hoists are those having a load-lifting capacity of 1.5, 3, and 5 t.

Force P applied to the rope in the case of a horizontal or inclined haulage of a load can be determined from the equation given below:

in a horizontal haulage

$$P_{hor} = fQ \tag{5.4}$$

in an inclined haulage

$$P_{incl} = Q\,(f \pm \alpha) \tag{5.5}$$

where f = friction factor
Q = load mass
$\alpha = H/L$ = coefficient of haulage (with plus sign at upward motion and minus sign at downward motion)
H = hoisting depth in metres
L = distance along inclined surface in metres

Breakaway forces P_{hor} and P_{incl} are 25 per cent greater. The friction factor may vary from 0.02 to 0.8 depending on the quality of rubbing surfaces.

Jacks (Fig. 5.10) are meant as auxiliary lifting mechanisms and haulage mechanisms used when heavy pieces of equipment, such as electrical machines, are to be moved over short distances (from 10 to 400 mm, as a rule). In the installation of electrical machines use is made of wedge, rack-and-gear, screw, hydraulic, and adjusting jacks.

The wedge jacks (Fig. 5.10*a*) depend for their operation on the opposing motion of two wedge-shaped plates at a rotation of the screw. The most widely used jacks of this type are those having a load-lifting capacity of 5 and 10 t at a hoisting depth of 15 and 10 mm and a mass of 5.5 and 13.5 kg, respectively. With the wedge jacks, the load lifting and lowering depths can be checked accurate to tenth fractions of a millimetre.

The rack-and-gear jacks (Fig. 5.10*d*) depend for their operation on the displacement of an intermediate spur gear

over a vertical rack, the tooth modulus of the latter being the same as that of the gear. The intermediate gear is driven by a gear engaged with the handle via a ratchet gear which serves as a back brake. While the handle is rotated the rack moves up and lifts the load with its crown. Another type of the rack-and-gear jack has its toothed rack secured on a fixed base while the rotating part is a fabricated lifting

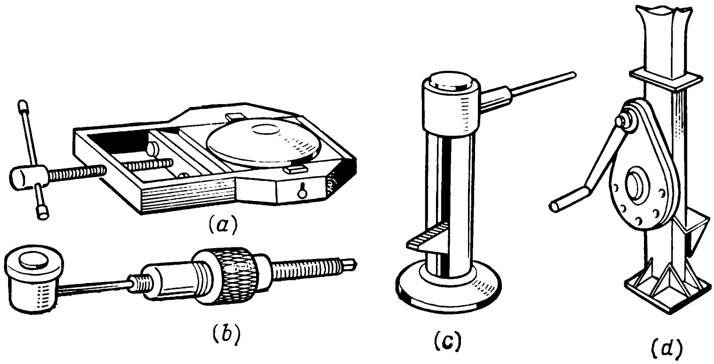


Fig. 5.10. Jacks
(*a*) wedge jack; (*b*) hydraulic jack; (*c*) screw jack; (*d*) rack-and-gear jack

case with a reduction gear. The bottom lug of the jack at tached to the upper head serves to support the load when the head proper cannot reach it in hoisting. For lowering the load it will be necessary to change over the ratchet pawl retainer and to turn the handle in the reverse direction. The rack-and-gear jacks of 3 and 5 t capacity are preferred for use in the installation of electrical machines. The hoisting depth of these jacks is up to 400 mm, the working effort applied to the handle is from 20 to 30 kg, the minimum height of the foot is 60 mm, the jack mass is 27 and 32 kg, respectively (heavier jacks of up to 50 kg are also available).

The screw jacks (Fig. 5.10*c*) are arranged so that the load screw rotates about a fixed nut attached to the jack body. The helix angle of the load screw is smaller than the angle of friction which affords self-braking of a lifted load. To facilitate manipulation with the handle, provision is made for a ratchet with a two-sided pawl and a ratchet wheel se-

cured on the top of the load screw. This jack is noted for its reliability and safety in operation (due to self-braking) as well as for smooth lifting and lowering of the load.

The screw jacks are classified as small-sized *bottle* jacks and *foot* jacks. The former have a load-lifting capacity of 2.5 to 5 t at a hoisting depth of 35 to 300 mm and a mass of 2.8 to 40 kg; the latter have a 5 to 20 t capacity at a hoisting depth of 180 to 350 mm, a mass of 20 to 92 kg, the foot length in the bottom position being 75 mm.

The load is usually lifted by two men who rotate the handle in the counter-clockwise direction. For moving the load down it will be necessary to rotate the handle in the reverse direction with the pawl retainer changed over.

Another variety of the screw jacks is an *adjusting* jack intended for levelling-off the bed plates of electrical machines and other pieces of equipment when they are mounted on a foundation. These jacks are available of types ДМ-3 and ДМ-5. Their load-lifting capacity is 3 and 5 t, the hoisting depth is 17 and 40 mm, the mass is 1.11 and 3.54 kg, respectively. The jacks depend for their operation on the rotation of the load screw about a movable nut which is fixed to the body and turned by a wrench about the body, the latter being held motionless with the aid of the other wrench.

The hydraulic jacks (Fig. 5.10*b*) function on the principle characteristic of the general hydraulic systems. The jack consists of three basic parts, *viz.* a body, a tank, and a pump. The working part is the body accommodating a piston and a sealing cup. The tank is a hermetically sealed vessel filled with fluid and accommodating a pump and a camshaft mounting a cam. The pump incorporates an intake and a delivery valves as well as a ram. During the left-hand (upward) motion of the ram the fluid is admitted through the valve while during its right-hand (downward) travel the fluid is delivered through the respective valve into the body (under the piston). The piston is forced upward thus lifting the load. The downward travel of the piston (and, hence, lowering of the load) takes place upon opening the hole blocked with a shut-off needle in which case the fluid is returned to the tank. A spontaneous downward travel of the piston (in case of a trouble) is prevented by fitting safety

gaskets in the form of semi-rings under the piston crown or by safety nuts screwed onto the piston. This is the operating principle of hydraulic jacks having a load-lifting capacity of 50 to 200 t.

The same principle is used in the other hydraulic jacks, such as those operated by a separate pump, and others. These hydraulic jacks are designed for lifting heavy machines and their parts over a small distance. The most extensively employed are hydraulic pumps of 10 to 200 t lifting capacity having the following characteristics: hoisting depth per one piston stroke—from 75 to 155 mm; height of jack in the lowered position—from 185 to 480 mm; mass—from 5.8 to 320 kg; maximum working pressure—40 MPa. Upon request, hydraulic pumps of a higher capacity, such as up to 750 t, can be available.

Small-sized hydraulic pumps (Fig. 5.10*b*) are most suitable for use in mounting electrical machines and their parts having a mass below 10 t.

Miscellaneous hoisting and haulage equipment (rocker arms, crabs, trestles, tripods, poles, booms, slide rails, as well as various jibs, cranes and the like) can be employed in the installation of electrical machines in addition to the above-described equipment.

The test and inspection standards and intervals for ropes, slings, hoists, fixtures, and other outfit used in the installation of electrical machines are specified in Chapter Twenty-Three (see Table 2.1).

CHAPTER SIX

Gauges and Instruments

A great number of measurements shall be made in the course of installation and wiring of the electrical machines. Simple linear measurements are made by means of graduated steel rules, folding metre rules, and measuring reels. Precision measurements of lengths, diameters, and clearances are made by means of multidimensional devices, such as slide gauges, micrometers, dial-and-indicator snap gauges, internal micrometers, special-purpose, wedge and multiplate feeler gauges.

The slide gauges (Fig. 6.1*a*) are used to measure the outer and inner diameters as well as the length of items measuring up to 2000 mm. The slide gauges consist of a rod *1* and measuring jaws *2*.

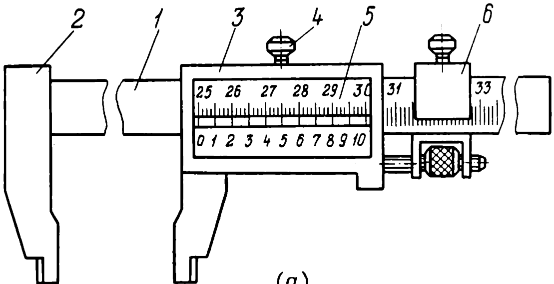
The rod is graduated and carries a slide *3* with a vernier *5*. The slide is locked in the desired position on the rod by means of a clamp *4*. Provision is made for a micrometer feed screw *6* for the slide.

Prior to taking measurements (for instance, in measuring the diameter of the shaft extension), the rod shall be released and the external measuring jaw is to be moved till both the jaws slightly compress the shaft. Then the micrometer feed screw is actuated to move the vernier slide to the part being measured, and the slide is locked in position by the clamp. Readings in millimetres are taken off the rod and in fractions of millimetres, off the vernier. The slide gauges provide for measuring accuracy of ± 0.05 to 0.1 mm.

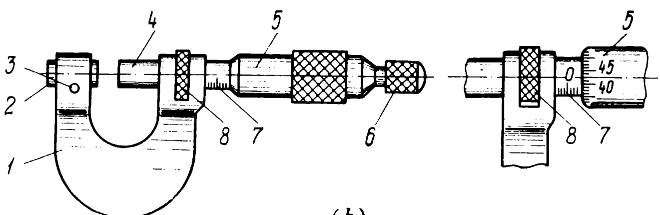
The micrometers (Fig. 6.1*b*) are meant for measuring the outer diameters of parts, such as shaft extension, and the length of items measuring up to 600 mm. Readings in millimetres and 0.5 millimetre are taken off the graduated

sleeve *7* and in fractions of millimetres, off the vernier thimble *5*.

Before taking measurements, it is required to turn off the locking screw *3* and lock washer *8* on the U-shaped frame



(*a*)



(*b*)

Fig. 6.1. Slide gauge (*a*) and micrometer (*b*)

1 and to move the anvil *2* till the zero divisions of the thimble and sleeve are aligned (with the measuring surfaces of the anvil coming in contact with those of the micrometer screw *4*). After that the locking screw shall be turned in and the anvil fixed in position.

The piece to be measured shall be slightly compressed with the measuring surfaces of the micrometer. To this end, the micrometer screw is rotated with the aid of a ratchet drive *6* till the latter starts slipping.

The dial-and-indicator snap gauges (Fig. 6.2*a*) are used for measuring the outer diameters and lengths of parts measuring up to 1000 mm. The snap gauge consists of a flat semicircular body *3* wherein a movable anvil *1* and an adjustable anvil *5* are installed together with the calibrated indicator-

and-dial arrangement *2*. The snap gauge is fitted with heat-insulating straps *4* to prevent the effect of warm hands on the accuracy of readings. The measuring accuracy of these gauges is ± 0.002 to 0.01 mm.

The internal micrometers (Fig. 6.2*b*) are used for measuring the inner diameters (for instance, the diameter of the half-coupling hub bore) or the clearance between surfaces.

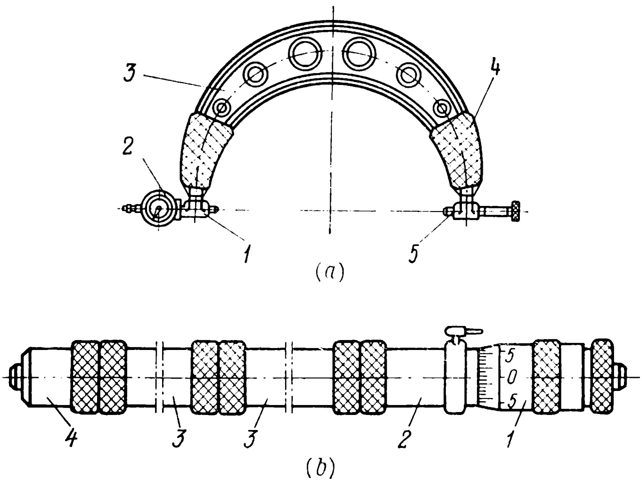


Fig. 6.2. Dial-and-indicator gauge (*a*) and internal micrometer (*b*)

The internal gauges are available with scale ranges of 50-75 to 400-10,000 mm. The internal gauges having a scale range of 1250-4000 mm and higher are fitted with two heads, *viz.* a micrometer head and an indicating micrometer head.

The internal micrometer consists of a tube *2* coupled with extension pieces *3* and a contact point *4* attached to the latter. The thimble of the micrometer head *1* is easy to rotate on a sleeve (not shown in Fig. 6.2*b*) secured within the other end of the tube. The measuring surfaces of the micrometer head and contact point are made of hard metal. The sleeve and the thimble are calibrated.

After the internal micrometer is set in a working position and the measuring surfaces of its micrometer head and contact point are brought in contact with the surfaces of

the half-coupling hub bore, the zero mark on the micrometer head thimble is aligned with the longitudinal mark on its sleeve. For measuring the bore diameter of the half-coupling hub, the internal micrometer is to be set strictly at right angle to the bore axis, otherwise it will give inaccurate readings.

When making measurements with the aid of an internal micrometer the effect of the room temperature shall be

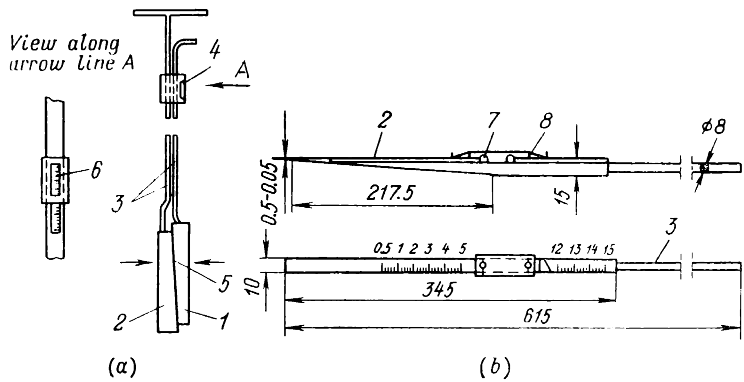


Fig. 6.3. Special (*a*) and wedge (*b*) feeler gauges

taken into account, especially when large diameters are to be measured (such as, the stator bore). Temperature fluctuations may bring about errors of several tenth fractions of a millimetre and greater still. Sagging of the internal micrometer due to its own mass is also liable to cause errors in reading. To this end, the internal micrometer shall be supported during measurements at the same points (the so-called Bessel points) which are to be found at a distance of two ninths the beam length from its ends.

The feeler gauges are used for measuring various clearances and gaps. The most universally used in the installation of electrical machines are special-purpose, wedge, and multiplate feeler gauges.

The special-purpose feeler gauges (Fig. 6.3*a*) are used for measuring large air gaps (10 to 20 mm) between the rotor and the stator. Such a feeler gauge consists of two wed-

ges *1* and *2* each attached to the respective rod *3*. The rods are free to move within a holder *4* carrying a vernier *6*. When measurements are made with such a feeler gauge, wedge *2* is introduced in gap *5* and wedge *1* is shifted till both the wedges are set tightly in the gap being measured, whereupon readings are taken off the vernier.

The wedge feeler gauges (Fig. 6.3*b*) are used for measuring air gaps of 0.5 to 12 mm accurate to 0.1 mm. Such a feeler gauge consists of wedge *2* attached to rod *3*. The pointed end of the wedge is 0.05 to 0.5 mm thick (Fig. 6.3). The upper surface of the wedge bears a calibrated scale along which slide *7* with index *8* is moved.

For measuring with this feeler gauge, wedge *2* is introduced in the air gap and slide *7* is brought to a position in which its taper portion rests against the butt end of the stator or rotor; readings are to be taken off the scale against index *8*.

The multiplate feeler gauges illustrated in Fig. 6.4 are meant for measuring clearances between the surfaces of half-couplings mounted on shafts being aligned as well as those between the taper end of the indicator rod (or alignment fixture pin) and the half-coupling rim. Such a feeler gauge *1* consists of calibrated plates *2* from 0.02 to 1 mm thick. The length of plates may be 100 or 200 mm. The feeler gauges with plates 100 mm long are supplied in four sets only, each set comprising from 9 to 17 plates. The feeler gauges with plates 200 mm long are available in the form of separate plates. The feeler gauge plates must enter the clearance or gap through a depth of not over 20 mm with a certain effort (or friction) which shall be approximately equal for all measurements.

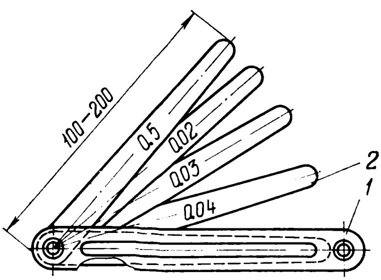


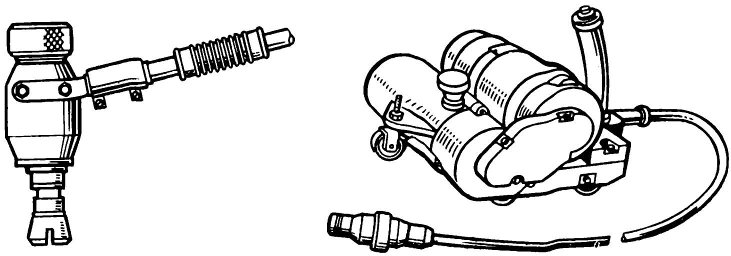
Fig. 6.4. Multiplate feeler gauge

Air-operated bush hammers and planetary electric mills are utilized in the arrangement of foundations for receiving the electrical machines.

The air-operated bush hammers (Fig. 6.5*a*) are used for cutting off hardened concrete of the foundation.

The planetary electric mills (Fig. 6.5*b*) serve for cleaning off the concrete surface of the foundation.

A number of special-purpose tools and instruments are used, in addition, in the installation of electrical machines. Among them are power-driven scrapers, level gauges, speed



(*a*) (*b*)

Fig. 6.5. Air-operated bush hammer (*a*) and planetary electric mill (*b*)

counters, tachometers, dial gauges, vibrometers, vibrographs, meggers.

The power-driven scrapers are used to scrape the surfaces of bearing shells and the surfaces at the splits of frames and pedestal bearings. These scrapers are manufactured with electric or air drives. The air-operated scrapers are more suitable for use in the installation of large and medium-size electrical machines because the electric scrapers have a number of drawbacks; so, any change in the direction of the scraper motion is accompanied by shocks; the number of scraper strokes per minute and the pressure on the tool cannot be adjusted.

The general arrangement diagram of an air-operated scraper is shown in Fig. 6.6. The basic parts of this tool are a body with a grip, an air motor, and a crank gear. Compressed air flows through hole *1* of the grip and through a control valve at a pressure of 0.4 MPa and reaches the motor stator *4* wherein it hits the four rotor blades and places the rotor in motion. The rotor speed can be adjusted within the range of 8000 to 12,000 r/min depending on the air feed.

The rotor incorporates a planetary train which consists of a gear *3* fixed in disc *2* and gears *14* rotating about the gear *3* on their own pins. The same pins carry gears *13* tightly fitted on them. These gears impart a rotary motion to a pair of conic gears via gear *5*. Such a planetary transmission affords a 10-fold reduction in the motor speed.

The cone train consists of gears *6* and *12* set in motion by gear *5*. The crank gear comprises a crankshaft *7* rotated

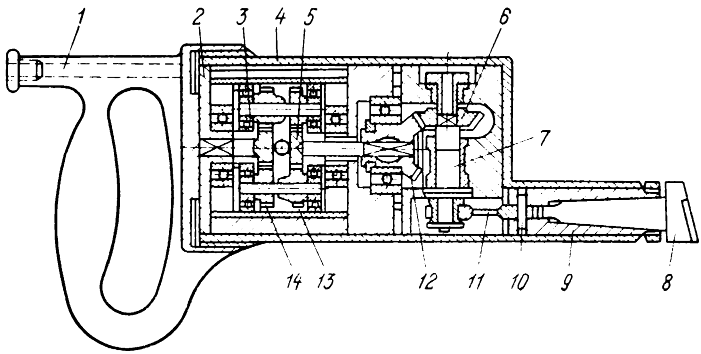


Fig. 6.6. Air-operated scraper

by gear *6* and a connecting rod *11* joined with slide *9* by means of spindle *10*. The scraper *8* is fixed in the conical hole of the slide and receives a reciprocating motion from the crankshaft. The air-operated scraper mass is 1.5 kg. This tool is simple in maintenance and reliable in operation.

The levels are used to level off the foundations, as well as bed plates, bearing pedestals, and other parts of electrical machines mounted thereon. The following types of levels are utilized in the installation of electrical machines: hydrostatic, frame, and micrometer-screw levels.

The hydrostatic level is meant for a coarse mounting and levelling of bed plates and bearing pedestals on a horizontal plane. This level consists of two glass tubes with cocks and a rubber pipe connection having a length to suit the space between the planes being measured. The glass tubes are secured to special supports to facilitate their handling.

In the course of operation with the level, the two glass tubes are first placed on the same plane close to one another and filled with fluid up to the zero mark. Then they are moved to the surfaces being levelled.

A difference in the levels of the surfaces is recognized by the displacement of the fluid from zero. Used as a fluid for these levels may be tinted water or transformer oil.

The hydrostatic level gives the more accurate indications, the greater is the distance between the points being levelled off. The accuracy of this instrument also depends

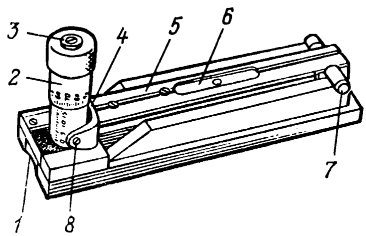


Fig. 6.7. Micrometer-screw level

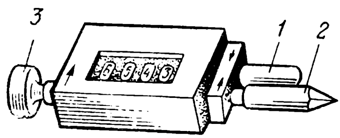


Fig. 6.8. Speed counter

on the skill of personnel dealing with the instrument, a correct watching of the fluid level in the tubes being essential. The diameter of the glass tubes shall be at least 10 mm so as to provide for a fluid surface within them as close to a plane as possible.

The frame levels containing a bulb with an air bubble measure 200 × 200 or 100 × 100 mm, the scale increment being from 0.02 to 0.3 mm. The scale increment is the angle of inclination of the bulb or the lift in millimetres per every metre corresponding to the displacement of the bubble within the bulb through one scale division. The frame bubble has flat working surfaces. Prismatic recesses are provided on the top, bottom, and one of the side surfaces.

The micrometer-screw levels (Fig. 6.7) are used for a precision measurement such as for determining the misalignment of shafts being centred.

The level base *1* has a unique shape of its sectional area which makes it convenient for fitting on a shaft. Fixed to the base is a post *2* with a micrometer screw *3* inserted

therein. The tube *5* holding bulb *6* is attached on one side to the vertically graduated bush *4* by means of screws *8* and on the other side, to the level base by means of screws *7*.

In order to determine a misalignment (downward deflection) of any surfaces the bubble in the bulb is brought to zero by means of the micrometer screw and then the degree of misalignment is read off the micrometer head. For checking the reading obtained the level shall be turned through 180° and fitted on the same place whereupon the measurement shall be repeated. The scale increment of the level is 0.1/1000 mm, i.e. one scale division corresponds to 0.1 mm rise per metre.

Prior to making measurements, the underside of the base and the surface to receive the level (such as, the shaft surface) are to be thoroughly wiped with a rag. The level shall not be tightly fitted to the surface under check as this may cause damage to the level. The level shall be kept away from heat sources so as not to disturb its sensitivity. At very high temperatures the bulb may break.

The speed counter (Fig. 6.8) is intended to measure the number of revolutions of a shaft within a definite time interval (for instance, within 0.25 to 0.5 or 1 minute). The counter comprises two spindles *1* and *2* for clockwise and counterclockwise rotation, and a reset button *3*.

The tachometer is used for measuring the shaft revolutions per minute. It has a reading dial and a selector intended for taking measurements within one of three or four ranges, such as, within 300 to 1200, 600 to 2400, 1000 to 4000 r/min.

The dial gauges are designed to check shafts and half-couplings being aligned, commutators, slip rings, and other rotating parts for correct shape and run-out.

The dial gauge is a direct-reading instrument with a clock-type movement (Fig. 6.9*a*). The dial gauge affords high accuracy measurements (0.01 and 0.005 mm). The movement consists of gear wheels which are arranged so that a 0.01 mm travel of the measuring stem *1* causes the dial gauge pointer to deflect through one division of dial *3*. Dial *5* shows the number of full swings of this pointer which corresponds to a 1-mm travel of the measuring stem. For setting the pointer to zero, the dial plate shall be turned by its rim *2* which is fixed in position by means of stop *4*.

For taking measurements (such as, for measuring the shaft journal run-out) the dial gauge is to be mounted on a vibration-proof fixed support (Fig. 6.9*b*) while the measuring stem is to be set normal to the shaft axis and slightly pressed on the surface. The shaft being checked is to be slowly rotated, and the run-out of the shaft journal is indicated by the pointer deflection. For instance, if the pointer deflects to the right on one half of the shaft journal

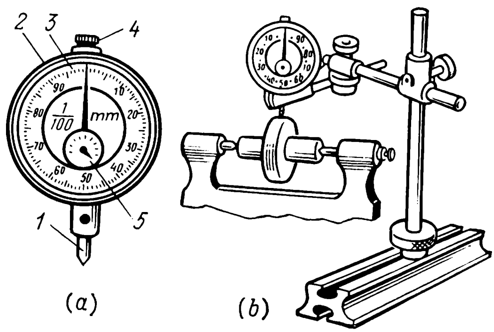


Fig. 6.9. Dial gauge
(*a*) external view; (*b*) measurement of run-out

circumference and to the left on the other half, it indicates that the journal runs eccentric. On the other hand, if the pointer deflects twice to the right and twice to the left as the stem is moved around the circumference, this points to an elliptical shape of the shaft journal.

The dial gauges are available with dials for measurement ranges of 0-2, 0-3, 0-5, and 0-10 mm.

The vibrometers (Fig. 6.10) are employed to measure the amplitude and direction of vibrations of electrical machines. The vibration amplitude is, essentially, a distance covered by the machine surface under test (such as, the surface of a half-coupling) from one extreme position to the other through an equilibrium position.

The vibrometer consists of a frame *1*, a heavy fulcrum *2* suspended from springs *3* in the frame, an indicator *4* built into the fulcrum and resting with its button *5* on a ring *6* which is secured to the frame, screws *7* intended to lock

the fulcrum in a desired position, and a carrying handle *8*. The indicator is free to rotate about its axis as the button can assume any radial position. Such an arrangement makes it possible to check the direction of the vibration amplitude and not only its magnitude. A tapped hole is provided at the bottom of the frame for fixing the instrument on the surface being tested.

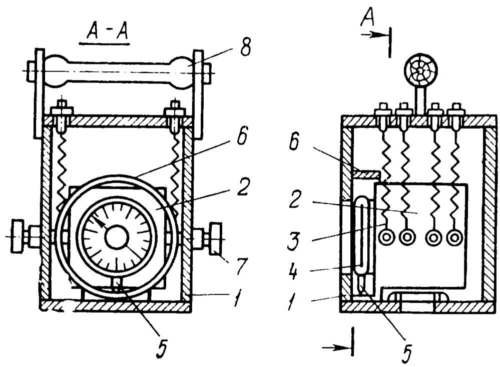


Fig. 6.10. Vibrometer

The large mass of the resiliently mounted fulcrum holds the latter motionless at any vibration of the instrument body, and the deflection of the body relative to the motionless mass is measured by the indicator.

Vibration shall be measured in three directions, *viz.* vertical, axial (along the machine axis), and transverse (in the horizontal plane normal to the machine axis).

Hand vibrographs shall be used for measuring vibrations of 0.05 to 6 mm in electrical machines rotating at a speed higher than 750 r/min.

The vibrograph (Fig. 6.11) consists of a transmitting linkage, a chart transfer mechanism, and a timer.

Shaft *1* (Fig. 6.11*a*) carries a pin *2* which comes in contact with the vibrating surface. The shaft is linked via a hinge *3* with a steel pen *4* which is free to turn about the handle axis.

Spring *6* serves to provide for the required contact between the pin and the vibrating surface. Provision is made for the

adjustment of the spring tension. The vibration curve is recorded with the tip of the pen which makes traces on paper chart *7* coated with wax. The chart is fed at a definite speed by means of a spring-wound clock-type mechanism. The timer marks every second on the chart, which makes it possible to determine the frequency of vibrations.

The general arrangement of the vibrograph is illustrated in Fig. 6.11*b*. The shaft *1* together with the pin travels in

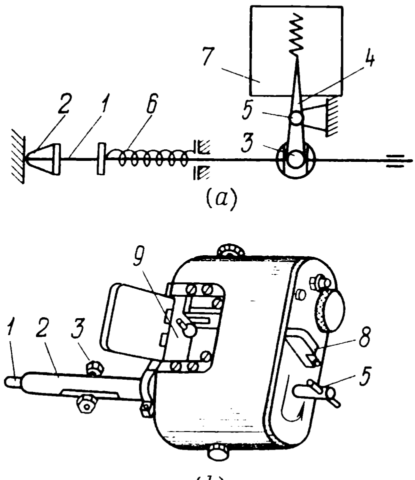


Fig. 6.11. Vibrograph

a guide tube *2*. The spring tension is adjusted by means of a screw *3*. A tumbler *8* is provided to turn on or off the chart mechanism and the timer. The clock spring is wound with a handle *5*. A port *9* is made in the instrument case to watch the pen movement. The instrument is furnished with a lever-type magnifier which is fitted on the tube and serves for 2- and 6-fold magnification of the recorded curve.

The megger is meant for measuring the insulation resistance (such as winding-to-winding and winding-to-earth insulation of electrical machines, bearing pedestal-to-foun-

dation insulation resistance, conductor-to-conductor and conductor-to-earth insulation resistance of supply cables, etc.).

The megger is a portable instrument indebted for its name to the unit of resistance measurement (megohm) (1 megohm = 1 million ohms).

The types M1101 and MC-05 meggers are most extensively used in the installation of medium-size and large electrical machines.

Figure 6.12*a* illustrates the most popular megger of the M1101 type. The megger consists of a self-contained dc sour-

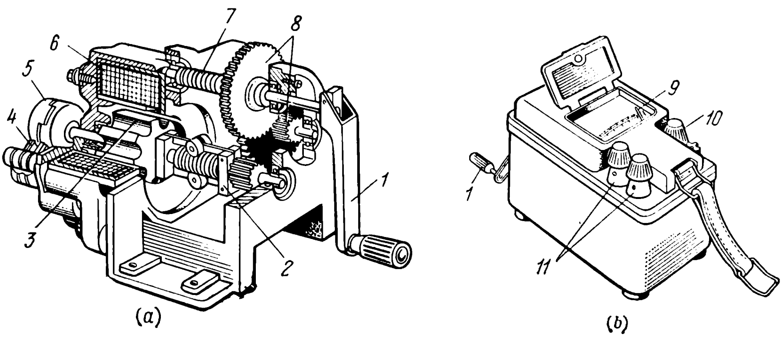


Fig. 6.12. Megger
(*a*) general arrangement; (*b*) external view

ce and a measuring circuit suitable for measuring high resistances.

A clockwise rotation of handle *1* sets in motion generator armature *3* via two pairs of gears *8*. The generator is, essentially, an eight-pole permanent magnet. A spring *7* is incorporated to disengage the mechanism as the handle is turned counter-clockwise. The permanent magnet is placed within a thin-wire multiturn cylindrical coil which is enclosed in a thin-walled iron piece whose lugs are bent down inside the coil. Through these lugs and the iron piece closes the magnetic flux created by the armature poles.

An ac voltage is induced in the coil *6* as the handle is rotated. The coil leads are connected to commutator bars

5. The commutator serves to convert alternating current of the armature into a direct current which is passed by means of brushes *4* to the meter coils via a set of resistors. The axle of these coils carries also a pointer which deflects by a certain angle depending on the value of resistance being measured.

Meter scale *9* (Fig. 6.12*b*) is calibrated in megohms and kilohms. The desired scale range is selected by turning knob *10* on the meter cover.

The meter readings vary with the generator voltage which depends on the armature speed. The meter incorporates a centrifugal speed governor *2* to maintain a constant rotational speed of the generator. As the meter handle is turned at a speed exceeding the rated value, the governor weights move apart under the effect of centrifugal forces and disengage the generator armature from the drive.

The type M1101* meggers are rated at an open-circuit voltage of 100 V (for 100-megohm scale range), 500 V (for 500-megohm scale range), and 1000 V (for 1000-megohm scale range). The type of a megger is to be selected depending on the characteristics of the equipment under test with due account for the scale range and rated voltage of the meter. According to the USSR State Standard (GOST) 11828-66, the type M1101 1000-V meggers shall be used for electrical machines rated 3.6 and 10 kV, while the type M1101 1000- or 500-V meggers shall be used for machines rated below 1000 V.

Before taking measurements, the megger shall be checked for condition. To this end, the meter shall be mounted horizontally, its terminals shorted out, and the handle rotated at a speed of 120 r/min. In the action, the meter pointer shall be set at scale zero. Then the drive handle shall be turned at the same speed with the meter terminals open. The pointer must stand at "infinity" on the scale. If the pointer overshoots in either direction by more than ± 1 mm, the megger shall be dispatched for testing at the first opportunity.

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* Since 1973 meggers of the M4100 type have been placed in production instead of the M1101 type. These meters have a scale range of 100, 500, 1000, 2000, and 2500 megohms.

Before connecting megger terminals *11* to a live piece of equipment under test, the latter shall be de-energized and its capacitance current shall be discharged.

Before measuring the insulation resistance of a cable line with two-sided supply (prior to connecting the electrical machine) measures shall be taken to exclude power delivery from the opposite side.

Protective earth shall be disconnected for the period of measurements.

For measuring the winding-to-earth insulation resistance, one of the megger terminals shall be connected to one of the winding leads and the other, to the machine frame or to earth; if the winding-to-winding insulation resistance is to be measured, the megger terminals shall be connected to the winding leads.

Connecting wires between the megger terminals and the piece of equipment under test shall have an appropriate length and good insulation. The grade ПВЛ flexible wires may be recommended for the purpose.

Another type of meggers in use is M503. These meggers are meant for connection to ac power supply through a step-up transformer and a selenium rectifier. These instruments are most suitable for obtaining absorption curves of insulation (see Chapter Twenty).

One more type of megger recommended for mentioned types of measurement is MC-2. This 2500-V megger is designed for connection to 127 or 220 V supply mains. The disadvantage of the M503 and MC-2 meggers is that they are not provided with a self-contained power source and can drain power from supply mains only.

The insulation resistance of thermal detectors shall be measured by means of meggers rated not higher than 250 V. The winding insulation resistance of electrical machines rated up to 500 and 1000 V is to be measured with 500- and 1000-V meggers, respectively.

According to the Regulations for electrical installations, high-voltage tests of insulation with a voltage of 1 kV at a frequency of 50 Hz may be replaced by one-minute insulation resistance measurements by means of a 2500-V megger. These meggers are likewise used for measuring the insulation resistance of 3 and 6 kV electrical machines.

In addition, miscellaneous instruments are used in the installation of electrical machines, *viz.*:

spring balance intended to measure the brush pressure and the loads on bearings of multimachine sets;

commercial tolyene and mercury *thermometers* with a scale range of up to 100 and up to 150°C, respectively, intended for measuring the winding temperature during insulation drying;

electrodynamic *voltmeters* with a scale range of 150-300 V used for checking the voltage across windings and other current-carrying parts during insulation drying;

moving-coil *ammeters* with a scale range of 150 A furnished complete with a 75-mV shunt and employed for measuring the current through windings and other current-carrying parts during insulation drying;

15-mV *millivoltmeters* meant for measuring the voltage drop across commutator bars of dc machines.

In addition to serial-production fitter's tools, such as miscellaneous wrenches, including universal adjustable ones, hammers of all kinds, pliers with insulated grips, anvil chisels, etc., use shall be made of tools for handling heavy items and for auxiliary jobs, including 12-kg hammers, steel crowbars, pickers, cross-cut and whip saws, chip axes, etc.

The number of tools is determined on site depending on the scope of work to be done and the size of machines being erected.

Special-purpose sets of instruments, tools and accessories shall be used for mounting medium-size and large electrical machines.

These sets comprise the following instruments, tools, and accessories: micrometer, type MK, scale range 0-25 mm, measuring accuracy 0.01 mm; set of internal micrometers, scale range 50-600 mm; set of feeler gauges, type I, scale range 1-100, 5-100, and type II, scale range 7-200; set of wrenches, size 8-36 mm; set of taper reamers, dia 13-27; set of indicating snap gauges, type C, scale range 300-800; shaft indicator, type I, measuring accuracy up to 0.01 mm; micrometer screw level, scale increment 0.1/1000 mm; non-adjustable frame level; hydrostatic level; wedge feeler gauge; wrench with changeable heads for large nuts; fitter's tool

kit; electric milling cutter; air-operated bush hammer; reamer for holes of half-couplings; tool for turning the shafts; shaft alignment fixture with electromagnetic holdfast and dial gauges; alignment fixture for machines with intermediate shaft; antifriction bearing puller (with strap and clip); universal three-arm puller; wedge jack, 50 t lifting capacity; hydraulic jack, 100 t lifting capacity; vibrometer, scale range 0.01 mm; centrifugal manual tachometer, type ИО-10; set of balance weights; set of slings; testing and marking V-blocks, 100-150 mm long.

CHAPTER SEVEN

Materials for Electrical Machine Installation

Different materials are required in the course of inspections, preparatory jobs, and installation of electrical machines. The largest group of these materials makes up those used for slushing and removal of slushing grease. These are gun grease УНЗ, grease УН (petroleum jelly), varnish No. 67, white alcohol, xylene, ethyl alcohol, clean calico cloth, gauze cloth, clean rags, waste, wax paper, aluminium foil, sackcloth, kerosene, varnish No. 26, etc.

Gun grease УНЗ is used for slushing the shaft journals and extensions, fitting surfaces in the hubs of half-couplings, fastenings, and other parts.

Grease УНЗ is composed of cylinder oil (35-25 per cent), petrolatum (60-70 per cent), grade 67 ceresin (5 per cent), and caustic soda (not more than 0.02 per cent). In appearance, this grease is a salvy compound of brown colour.

The grease shall be tested prior to use. A 1-mm layer of grease applied on a glass plate and examined in the light must show a uniform compound free from lumps (a fine granularity may be admitted). The grease is to be also tested for its protective properties. This test is to be made in a laboratory. Two plates made of steel 40 or 50 are dipped in grease contained in a porcelain cup so that at least a 4- or 5-mm layer be above the plates. The cups with these plates are placed in a desiccator on a glass plate or a perforated porcelain disc. The desiccator is closed with a cover bearing a filter pressboard disc on the underside. The grease shall be rejected if condensate is detected in the cup. Anti-corrosive properties of the grease are determined by the condition of the upper horizontal surface of each steel plate.

Grease УН (petroleum jelly) is used as an anti-corrosive coating for the core legs of apparatus magnetic systems.

This grease is composed of petrolatum, wax, ceresin, industrial and cylinder oil, still residues of instrumental oils, and heavy distillate wax and ceresin melted together in any proportion. In appearance, grease УН is a homogeneous lump-free compound of light-brown to dark-brown colour.

The УН grease shall be subjected to the same tests as the УНЗ grease.

Varnish No. 67 is used for coating the bed plates of electrical machines (with the exception of surfaces to be armour-plated) to protect them against corrosion. The No. 67 varnish is, essentially, a petroleum asphalt solution with a hard petroleum pitch or asphalt additive. The varnish composition is as follows: 39 per cent of petroleum asphalt; 47 per cent of pure benzene; 10 per cent of turpentene oil; 4 per cent of white alcohol. The dry-hard time of the varnish at a temperature of 20 ± 2°C is 30 minutes, the dry-tack-free time is 2 hours.

The No. 67 varnish is delivered to the User in glass bottles holding 10 to 30 litres or in wooden barrels treated inside with jointer's glue and holding 50 to 80 litres. The bottles are tightly closed with cork or wooden stoppers. The bottle neck is wrapped over the stopper with a piece of cloth, tied with a twine and sealed. The bottles are placed in baskets or crates; the bottom of the basket or crate as well as the space between the bottles are filled with straw or shavings. The baskets shall be provided with carrying handles.

The No. 67 varnish is an inflammable material, therefore, safety rules shall be strictly observed when using it. Workers dealing with this varnish shall be instructed by the engineer in charge or the foreman on appropriate safety precautions.

White alcohol (petrol-solvent for varnish industry) is used as a solvent for the removal of slushing grease from the shaft journals of electrical machines. The white alcohol is, essentially, a petrol distillate. Prior to use, it shall be tested as follows. When poured in a jar of 40 to 50 mm in diameter, the white alcohol shall be clear and free from suspended bodies and sediments, including water drops.

Pure coal-tar *xylene* is used as a solvent for the removal of anti-corrosive coatings from the shaft journals, half-couplings, fastenings, etc. Xylene is a clear colourless li-

quid in appearance. The xylene, when tested in the same way as white alcohol, shall be clear and free from suspended bodies and sediments, including water drops.

Commercial (hydrolyzed) *ethyl alcohol* is used for wiping the shaft journals just cleaned of anti-corrosive coatings. Ethyl alcohol is, essentially, a fermentation product of sugars formed as a result of hydrolysis of wood, vegetable waste, or softwood sulphate boiling. In appearance, the ethyl alcohol is a clear colourless liquid free from apparent impurities. Prior to use, it shall be subjected to the same test as white alcohol and xylene.

Ethyl alcohol is an inflammable material. It is supplied to the User in airtight and sealed metal barrels bearing appropriate warning inscriptions. Ethyl alcohol shall be stored in store houses in special metal tanks, observing regulations for alcohol storage. Workers dealing with ethyl alcohol shall be familiarized with safety regulations.

Clean calico or *gauze* shall be used for wiping the shaft journals, slip rings, commutators, and other parts of electrical machines just after the removal or before application of slushing grease.

Clean rags and *waste* shall be used to remove slushing grease and to wipe the machine parts.

Wax paper and *aluminium foil* are intended for wrapping the shaft journals coated with gun grease.

Sack cloth is utilized as a preservative material for shaft journals and half-couplings.

Kerosene is used for cleaning the shaft journals of slushing grease and for thinning the ГОИ paste.

Varnish No. 26 is utilized for coating the sackcloth to prevent its moistening.

In addition to the above-described materials use is made of the ГОИ paste for polishing the shaft journals; sand cloth for grinding the shaft journals; felt for grinding the shaft journals; pressboard, leather, and chalk for polishing the shaft journals; coloured chalk or pencils for making marks on the half-couplings in the course of alignment of shafts; note-books for entering the results of alignment of shafts. For hoisting and haulage operations use is made of sleepers, steel-wire and hemp ropes described in detail in Chapter Five.

CHAPTER EIGHT

Tolerances, Fits, and Allowances

8.1. General

Electrical machine parts rotating at a high speed have a heavy mass. A trouble-free operation of electrical machines and their long service life will be ensured by high-accuracy finish of their shafts, half-couplings, and other rotating parts, by compliance of their actual dimensions with rated values, as well as by proper installation and wiring. These factors are likewise essential for other parts of electrical machines, such as stators, bearing pedestals, bearings, etc.

A number of factors cause deviations from rated dimensions in the course of finishing these parts, such as, inaccurate setting of a cutting tool or part being treated in the machine tool; unsatisfactory or worn-out equipment; inaccurate readings of measuring instruments; rough machined surfaces of parts; effect of thermal expansion; sagging of parts under the action of their own mass, etc.

Hence, the desired dimensions of a part can be obtained within certain limits of accuracy whatever be the type of treatment. These limits are determined according to technical conditions (purpose of the machine) and economic considerations (cost of treatment).

In order to avoid arbitrary deviations from rated dimensions and to keep these deviations within definite limits, extreme dimensions (or limits of size) have been specified.

The extreme dimensions are the maximum and minimum limits for the actual dimension. Hence the terms maximum extreme dimension and minimum extreme dimension.

The algebraic difference between the actual dimension and its nominal size is termed *deviation* which can be either over the nominal size (upper deviation) or under the nominal size (lower deviation).

The upper deviation is an algebraic difference between the maximum extreme dimension and the nominal dimension.

The lower deviation is a difference between the minimum extreme dimension and the nominal size.

The upper deviation is indicated with sign "+" and the lower deviation, with sign "—".

The upper deviation is given in drawings as a superscript at the nominal value and the lower deviation, as a subscript. Example:

$$160^{+0.2}_{-0.1};\ 180^{+0.1}_{-0.2}$$

If both the deviations are equal in magnitude, they are designated with sign "±". Example: 100 ± 0.1 instead of $100^{+0.1}_{-0.1}$.

Tolerance is the difference between the maximum and minimum extreme dimensions.

Example. The nominal dimension of the shaft is 350 mm, the upper deviation is 0.02 mm, the lower deviation is — 00.1 mm. The tolerance will be 0.02 — (—0.01) = 0.03 mm.

When two parts are to be assembled so that one part is inserted into the other, such parts are distinguished as a male part and a female part.

The female part of round bodies is called a *hole* (such as the half-coupling bore to be fitted on the shaft) while the male part is called a *shaft* (such as the shaft to receive a half-coupling). Fig. 8.1 shows the extreme dimensions of the hole and shaft. The difference between the hole and shaft diameters determines the type of joint and the fit.

Positive allowance or *clearance* is the positive difference between the hole and shaft dimensions (the hole dimension is greater than that of the shaft). When there is a positive allowance (Fig. 8.2), the dimension of the female part is larger than that of the male part. The positive allowance value characterizes the degree of freedom for the mating parts to move after they are assembled.

Figure 8.2 shows two extreme values of positive allowance, *viz.* maximum one, *a*, existing when the hole has a maximum extreme dimension *A*, while the shaft has a minimum extreme dimension *B*, and a minimum positive

allowance, *b*, for the case when the shaft has a maximum extreme dimension *C* while the hole extreme dimension *D* is minimum.

Negative allowance or *interference* is a positive difference between the shaft and hole dimensions (the shaft dimension

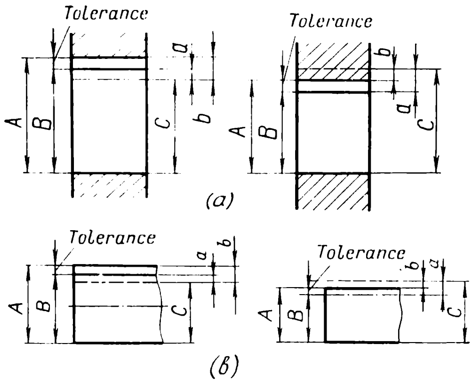

Fig. 8.1. Extreme dimensions for holes (*a*) and shaft (*b*)
A — maximum; *B* — minimum; *C* — rated; (*a*) lower deviation; (*b*) upper deviation

is greater than that of the hole). When there is a negative allowance, the male part dimension (prior to assembly) is greater than the female part dimension (Fig. 8.3). The negative allowance characterizes the amount of interference that is present when the mating parts are assembled. Fig. 8.3 shows two extreme values of negative allowance, *viz.* a minimum allowance *a* for the case of a minimum extreme dimension *A* of the shaft at a maximum extreme dimension *B* of the hole and a maximum allowance *b* for a minimum extreme dimension *C* of the hole and a maximum extreme dimension *D* of the shaft.

The type of joint according to positive or negative allowances is defined as *fit*. The fit between two mating parts is the relation existing between them with respect to the amount of clearance or interference that is present when they are assembled.

Fits are divided into three types:

(a) clearance fit which is one providing a clearance when mating parts are assembled;

(b) interference fit which offers an interference when mating parts are assembled;

(c) transition fit having limits of size so prescribed that either a clearance or an interference may result when mating parts are assembled.

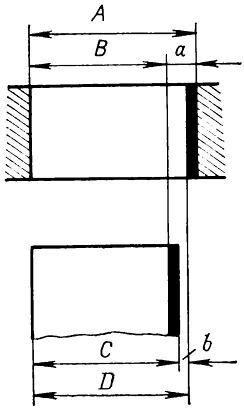

Fig. 8.2. Positive allowances or clearances

a — maximum; b — minimum; A— maximum extreme hole dimension; B — minimum extreme shaft dimension; C — maximum extreme shaft dimension; D — minimum extreme hole dimension

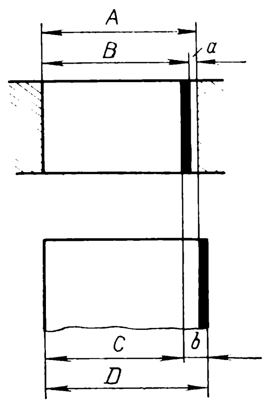

Fig. 8.3. Negative allowances or interferences

a — minimum; b — maximum; A— minimum extreme shaft dimension; B — maximum extreme hole dimension; C — minimum extreme hole dimension; D — maximum extreme shaft dimension

The maximum and minimum positive (or negative) allowances are two extreme values within which a clearance (or interference) is specified.

Allowance for fit is a parameter characterizing the difference between the maximum and minimum clearances or interferences for clearance and interference fits, respectively. Two allowance systems are specified, *viz.* a hole system and a shaft system.

With the hole system, the hole dimensions are constant for every nominal size and accuracy grade, while the extreme dimensions of the shaft are different for different types of fit. With the shaft system, the shaft dimensions are constant for every nominal size and accuracy grade, while the extreme dimensions of the hole depend on the type of fit.

The nominal size of fit in the hole system is determined by the minimum extreme dimension of the hole, and its margin tolerance is towards the increase of the hole, i.e. directed into the part body.

The nominal size of fit in the shaft system is the maximum extreme dimension of the shaft, and its margin tolerance is towards the decrease of the shaft dimensions, i.e. directed into the shaft body.

Different types of fits and allowances are grouped into grades according to the tolerances of holes and shafts. The following seven accuracy grades are specified by standards for parts of up to 500 mm in diameter depending on the accuracy of finish or margin tolerance: 1, 2, 2a, 3, 3a, 4, and 5, grade 1 being the highest of them. The following six accuracy grades are specified for parts of a diameter exceeding 500 mm: 2, 2a, 3, 3a, 4, and 5, grade 1 being the highest of them.

The hole system is designated with letter A and the shaft system, with letter B, the accuracy grades being given by the respective subscripts.

Example: the hole systems of accuracy grades 1 and 4 are designated A_1 and A_4, respectively; the shaft systems of accuracy grades 1 and 5 are designated B_1 and B_5, respectively. The numerical subscript is omitted for accuracy grade 2.

The most popular in the installation of electrical machines is the hole system of accuracy grade 2.

This system employs the following types of fits*: force fits (Гр), heavy-drive and medium-drive fits (Пр), light-drive fit (Пл), locational clearance fit (Г), locational transition fit (Т), locational interference fit (Н), push fit (П), close-sliding and sliding fits (С), precision-running and close-running fits (Д), free running fit (Л), loose running fits (Ш and ТХ).

The *interference fits* may be of an expansion or contraction type (in the former case the female part is heated, in the latter case the male part is cooled down), or a combination of both. The interference fit ensures a guaranteed negative

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* For approximate English equivalents of Russian fits refer to Appendix 11.

allowance between mating parts after they are assembled. Such a fit does not require any locking devices (keys, locking screws, etc.) and the joint is tight enough to exclude mutual displacement of parts.

In the case of *transition fits*, a tight joint is obtained through the use of miscellaneous fixing devices. With this type of fit either a clearance or an interference may result when the mating parts are assembled.

In the case of *clearance fits* a guaranteed clearance is ensured between the mating parts which makes them free to move relative to one another.

The interference fits of grade 2 include: force fits (Гр), heavy drive and medium drive fits (Пр), light drive fit (Пл); the transition fits are as follows: locational clearance fit (Г), locational transition fit (Т), and locational interference fits (Н) including the push fit (П); the clearance fits are as follows: close sliding and sliding fits (С), precision running and close running fits (Д), medium running fits (Х), free-running fit (Л), loose running fits (Ш and ТХ).

8.2. Tolerances, Fits, and Allowances in Electrical Machine Installation

In the installation of electrical machines (for instance in checking the fitting dimensions of shaft extensions for correspondence to the bores in hubs of half-couplings) fits and allowances of accuracy grade 2 specified in Tables 8.1 and 8.2 shall be referred to.

Half-couplings of machines intended for heavy-duty operation, such as drives of roll stands, etc., are to be shrunk on the shafts while hot with a negative allowance affording a tight fit. The negative allowance may be considered adequate in case the hole diameter in the hub of a half-coupling shrunk while hot onto the shaft is smaller in the cold state than that of the shaft extension by 0.08 to 0.01 mm per every 100 mm of the shaft diameter.

Example. For a shaft of 500 mm in diameter, the hole in the half-coupling hub shall have a diameter (0.08-0.1) $\times$ 5 = 0.4-0.5 mm smaller than the diameter of the shaft, i.e. it shall measure 499.5-499.6 mm. To facilitate further calculations, only a single diameter (499.5 mm) will be taken; then the negative allowance will be 500 - 499.5 = 0.5 mm.

Table 8.1

Allowances and Fits for Accuracy Grade 2 Hole System

Nominal diameters, mm	Permissible deviations for hole, μ		Force fits (Гр)		Locational clearance fit (Г)		Locational transition fit (T)		Locational interference fit (H)		Push fit (П)	
			Permissible deviation for shaft, μ									
	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower
80-100	+35	0	+140	+105	+45	+23	+35	+12	+26	+3	+12	—12
100-120	+35	0	+160	+125	+45	+23	+35	+12	+26	+3	+12	—12
120-150	+40	0	+190	+150	+52	+25	+40	+13	+30	+4	+14	—14
150-180	+40	0	+220	+180	+52	+25	+40	+13	+30	+4	+14	—14
180-220	+45	0	+260	+215	+60	+30	+45	+15	+35	+4	+16	—16
220-260	+45	0	+300	+225	+60	+30	+45	+15	+35	+4	+16	—16
260-310	+50	0	+350	+300	+70	+35	+50	+15	+40	+4	+18	—18
310-360	+50	0	+400	+350	+70	+35	+50	+15	+40	+4	+18	—18
360-440	+60	0	+475	+415	+80	+40	+60	+20	+45	+5	+20	—20
440-500	+60	0	+545	+485	+80	+40	+60	+20	+45	+5	+20	—20

Table 8.2

Allowances and Fits for Accuracy Grade 2 Shaft System

Nominal diameters, mm	Permissible deviations for shaft, μ		Force fits (Гр)		Locational clearance fit (Г)		Locational transition fit (T)		Locational interference fit (H)		Push fit (П)	
			Permissible deviation for hole, μ									
	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower
80-100	0	—20	—93	—140	—40	—45	0	—35	+9	—26	+23	—12
100-120	0	—23	—113	—160	—40	—45	0	—35	+9	—26	+23	—12
120-150	0	—27	—137	—190	—12	—52	0	—40	+10	—30	+27	—14
150-180	0	—27	—167	—220	—12	—52	0	—40	+10	—30	+27	—14
180-220	0	—30	—200	—260	—15	—60	0	—45	+11	—35	+30	—16
220-260	0	—30	—240	—300	—15	—60	0	—45	+11	—35	+30	—16
260-310	0	—35	—285	—350	—18	—70	0	—50	+12	—40	+35	—18
310-360	0	—35	—335	—400	—18	—70	0	—50	+12	—40	+35	—18
360-440	0	—40	—395	—475	—20	—80	0	—60	+15	—45	+40	—20
440-500	0	—40	—465	—515	—20	—80	0	—60	+15	—45	+40	—20

At such a difference in diameters a sufficiently high interference is created to ensure a tight fit. The negative allowance shall be held within specified limits, for if it is too large, the hub may break, and if it is too small, the half-coupling may slip on the shaft at heavy torques.

This rule is in full compliance with standards for negative allowance used in mechanical engineering and given hereunder in Table 8.3.

Table 8.3

Negative Allowances for Accuracy Grade 2 Hole System at Force Fit

Rated shaft diameter, mm	Negative allowance, μ		Rated shaft diameter, mm	Negative allowance, μ	
	maximum	minimum		maximum	minimum
50-65	105	45	180-220	260	170
65-80	120	60	220-260	300	210
80-100	140	70	260-310	350	250
100-120	160	90	310-360	400	300
120-150	190	110	360-440	475	355
150-180	220	140	440-500	545	425

For instance, as specified in Table 8.3, the negative allowance for a shaft of 500 mm in diameter shall be maximum 0.545 mm and minimum 0.425 mm or, in average, 0.485 mm, according to the hole system of accuracy grade 2. Then the hole of the half-coupling hub shall be $500-0.485 = 499.515$ mm which is in full compliance with the specified standard.

It is good practice to measure the hole dimensions in the hub of a hot half-coupling by means of a special templet made in the form of a round disc, 3-5 mm thick, with a grip welded to it.

The templet diameter shall be larger than the diameter of the hole in the hub of the cold half-coupling by three negative allowances.

For the above-considered example, the templet diameter shall be $499.5 + 0.5 \times 3 = 501$ mm.

CHAPTER NINE

Installation of Heavy Machines and Parts

Installation of heavy pieces of equipment involves their slinging, attachment, horizontal, vertical, and inclined haulage by means of manual and power-operated facilities, maintenance, adjustment, and outfitting of miscellaneous hoisting and handling mechanisms, selection of methods for setting these mechanisms in the working position, manufacture of slings, termination and stranding of ropes, tying of fastening knots, tests of hoisting and haulage equipment.

Some of these operations and methods thereof are given in Chapter Five of this Book covering the fixtures, tools, and facilities for handling and hoisting the electrical machines.

This Chapter deals only with operations specific to the installation of electrical machines, and large ones in particular.

Heavy machines and their parts must be handled with utmost care so as to ensure their good condition after installation.

In store houses and on storage sites the electrical machines are usually handled by a special crew of the store house personnel who are skilled in the art of moving heavy equipment. In the course of installation the electrical machines shall be handled by the electricians who install the machine and are skilled in the job. These men shall have a special Certificate or a note in the general Certificate stating their qualification in handling heavy items. In most important cases handling of electrical machines and their parts as well as management of the crew must be entrusted to a skilled rigger or foreman. In all cases, however, heavy and important machines or parts shall be handled under the supervision of a specially assigned engineer.

Prior to starting the haulage of heavy items make sure that

the hoisting and haulage equipment has been duly inspected and tested by appropriate agencies and that the effective period of tests has not yet expired.

In handling the electrical machines observe warning inscriptions on packing containers or on parts delivered without packing, such as "Sling here", "Handle with care", "Do not turn over", etc.

Handling of heavy, long, and important electrical machines on their way to the installation site shall be carried out in compliance with the construction work organization plan (CWOP) or the progress plan (PP) worked out by the Designer and approved by the Contractor and User. The construction work organization plan and the progress plan stipulate places of intermediate storage, transport and hoisting facilities, freight traffic volume, etc.

At the installation sites the electrical machines and parts are to be handled in compliance with the installation and wiring progress plan (IPP) worked out by the organization responsible for the installation and wiring of the electrical machines. The "Heavy Equipment Haulage" section of this plan envisages freight traffic volume, transport and haulage facilities to suit the mass of the machines and their parts, unloading and storage sites for the machines and parts, assembly sites with lay-out diagrams, mounting recesses. Whenever a necessity arises to unload or place electrical machines or their parts on hung floors, the points on the latter suitable to receive heavy loads are to be indicated in the IPP, this being previously coordinated with building contractors with due account for permissible specific loads per unit area (1 m^2) at different places on the hung floor. Separate areas on the hung floor may be reinforced, if necessary.

Additional thrusts applied to the building structures as a result of heavy equipment haulage, the magnitude of these thrusts, the direction and point of their application shall be in full compliance with reference drawings or the IPP.If such indications are not specified, the application of additional thrusts shall be coordinated, in a written form, with the building contractor officials. The IPP also specifies the lay-out of hoisting and haulage equipment for the installation of heavy machine parts.

Handling loads with the aid of two cranes shall be admitted only upon a written permission of the installation administration chief engineer and shall be carried out under the supervision of a specially assigned engineer.

In the absence of an installation and wiring progress plan do the following before starting the haulage of heavy items:

determine the mass of the load to be lifted and the load-lifting capacity of the available hoisting and haulage equipment. Never use hoisting and haulage facilities for handling loads exceeding their rated capacity;

obtain a permission, in a written form, for the application of additional thrusts on the building structures;

check the areas on the hung floors, meant to accommodate the machine parts prior to assembly, for ability to take additional thrusts and reinforce these areas, if necessary.

When hoisting electrical machines or their parts, slings shall be attached to them neatly, without sharp bends, knots, or spinnings, and after the slings are tensioned, they shall be examined for correct positioning so that the load should not turn over when being hoisted. In the event of incorrect position of the load a signal shall be sent to move it down whereupon the slings shall be attached correctly. The load hook of the hoisting gear shall be positioned above the centre of gravity of the load to be tested. It is inadmissible to pull the machines in the event of non-uniform tensioning of the ropes.

Slings shall be attached by means of eye-bolts, eyelets, false pipes or other special arrangements (Fig. 9.1) such as lifting beams, yokes, distance pieces. When hoisting machine parts having sharp ribs (edges), the slings shall be set on shims at these places so as to protect them against bends and wear, or use shall be made of slings fitted with stock spacers (Fig. 5.3*e*). It shall never be allowed to secure slings to the machined surfaces. If special slinging arrangements are not available, slings may be attached to basic parts of the machine frame or bed plate. In this case the surfaces contacting the slings shall be separated from the latter by means of wooden, rubber, or other soft spacers so as to exclude any injury. To prevent damage to the machine painted or varnished surfaces, rubber mats or rags shall be fitted at the places where they are gripped by slings.

Heavy machines or parts shall be first lifted to a height of about 200 mm and examined once more in this position for the condition of hoisting facilities by manually pushing every leg of the sling so as to make sure that they are uniformly tensioned. Then the hoisting gear brakes shall be checked and only after that the machine may be lifted to the desired height.

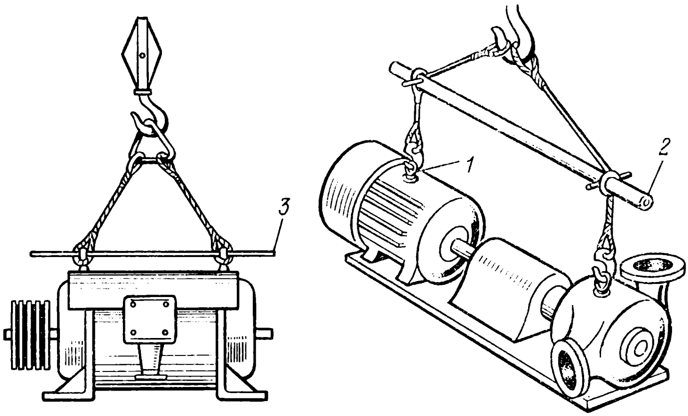


Fig. 9.1. Slinging the machines
1 — eye-bolt; 2 — lifting beam; 3 — crow-bar

Particular care shall be taken when slinging and handling large electrical machines so as to prevent damage to their armature or rotor electric steel stacks, windings, slip rings, commutators; it shall be borne in mind that any slight injury unnoticed during external examination may cause failure of the machine in the course of operation. The armature or rotor stacks shall never be directly gripped by slings. When it is required to sling these parts, it will be a good practice to place distance boards or soft spacers under the sling parallel to the rotor or armature axis. When a sling is to be attached to the rotor shaft, it shall be slipped thereon from both sides of the rotor so as not to touch the shaft portions meant to mount the bearings. In order to prevent damage to the slip rings and windings by tensioned slings, either wooden distance pieces shall be placed be-

tween them or the rotor shall be lifted by means of a special lifting beam (see Fig. 5.7). A large-diameter rotor may be lifted by means of slings hooked on special bars which are to be inserted in the rotor spider. Wooden spacers are to be placed under the bars so as to prevent damage to the rotor windings and a wooden distance piece or a lifting beam shall be fitted between the slings. If it is required to attach slings directly to the rotor core, the latter shall be covered on all sides with wooden planks, care being taken to prevent contact of the steel-wire rope with the rotor iron.

The lifting beam illustrated in Figs. 5.7 and 9.1 shall be used for slinging assembled motor-generator sets or long parts to prevent additional bending stresses on the shaft or other long parts of machines.

Removal of slings after the load has reached the assigned place shall be made after the machine or part is set steadily in position. The machines or their parts shall never be dropped in unloading, whatever precautions were taken to ensure their safety.

In case hoisting facilities are not available on the site of installation or their use is impossible, heavy machines, sets, or parts delivered thereto can be unloaded from a freight car or a trailer on a stack of sleepers (Fig. 9.2). To this end, rails or beams are placed with one end on the flat car and with the other, on the stack of sleepers or on a trestle. When a load is mounted on beams, rails are to be fitted under the load. The latter can be lifted by means of four jacks, if necessary, and after the ends of rails or beams are inserted underneath, the load is to be lowered onto the rails. Rails are to be placed so as to exclude their movement lengthwise. The rail heads shall be coated with a solid oil-and-graphite compound. After the preparatory work is over the load is to be slowly pulled with a winch off the flat car over the rails onto the stack of sleepers or onto a trestle. In the action, care shall be taken to move both the ends of the load at the same speed. In the same way the machine can be moved over rails or beams from the stack of sleepers or from the trestle onto the foundation which already mounts the bed plate and is ready to receive the machine. If the stack of sleepers is not arranged in close proximity to the

foundation, the machine shall be first pulled off the stack of sleepers onto mounting skids, a steel sheet or any similar arrangement. For lowering the machine, two additional stacks made of beams shall be arranged on both sides of the main stack. Then the machine is to be lifted by means of jacks mounted on the additional stacks and, as soon as the main stack is set clear, one or two rows of sleepers (depend-

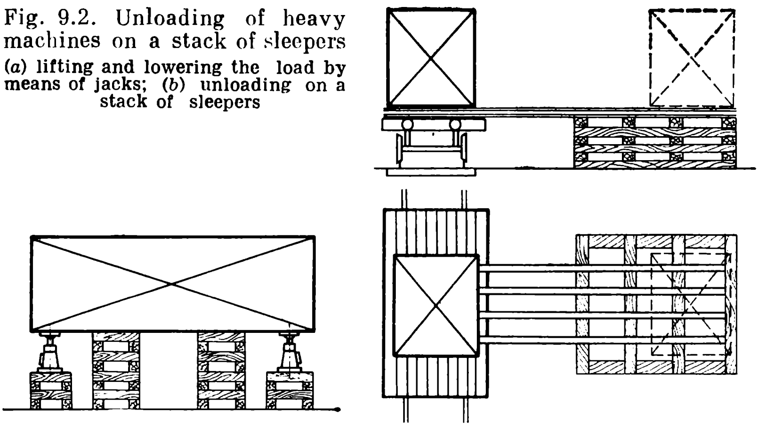


Fig. 9.2. Unloading of heavy machines on a stack of sleepers
(*a*) lifting and lowering the load by means of jacks; (*b*) unloading on a stack of sleepers

(*a*) (*b*)

ing on the working stroke of the jack) shall be removed and the machine is to be lowered by the jacks onto the main stack. Then it will be necessary to take a few beams from under the jacks so as to provide another working stroke for the latter; the jacks are to be set in the working position and the machine shall be slightly raised so as to clear the upper sleepers of the main stack (Fig. 9.2*a*), etc.

Heavy machines are usually hauled on skids with rollers placed underneath. The rollers are usually made of steel pipe lengths having a diameter of 80 to 100 mm or of smooth wooden logs. The rollers are to be equally spaced 0.5 to 0.8 m apart. The skid-mounted machine is to be hauled over rollers by means of the traction rope of a winch placed at a certain distance from the machine. If the surface under the rollers is rough or insufficiently rigid, the machine path shall be covered on both sides with planks, 40 or 50 mm

thick, or with sleepers. As the rear rollers are cleared, they shall be carried ahead and fitted under the skids. For turning the machine the front rollers are to be set at an acute angle to the skids.

A machine placed on a steel sheet is hauled by a tractor. The machines are usually hauled and lifted in the course of installation with the aid of overhead travelling cranes, jib cranes, derrick cranes, and hoists with winches, tackle blocks, etc.

A commander in charge (a foreman or a crew leader) shall be assigned before hoisting heavy machines. All the men engaged in the job shall be instructed on their duty and an appropriate entry shall be made in the instruction book. All the workmen, including crane operators and motor-mechanics, shall implicitly obey the commander in charge of hoisting, as any insubordination may lead to accidents and drop of the load. It is a common practice that heavy items are handled under the command of a single, specially assigned person. It can be a foreman, a crew leader, a slinger, an electrician well acquainted with haulage technique and commands, depending on the mass of load and haulage conditions. During haulage operations intervention of any other commanders is inadmissible, with the exception of emergency conditions.

During hoisting the machine is adjusted in the desired position and turned on the hook by means of steel-wire span ropes fastened to the machine. In the case of small loads hemp ropes are used for the purpose.

Hoists or crane operator's cabins shall be positioned so that the commander in charge or slinger could send sign or voice signals directly to the crane or hoist operator, tractor driver, or mechanic.

The machine shall be lifted gradually, without jerks and rocking, avoiding knocking against surrounding objects, such as walls, columns, trusses, pieces of equipment, etc. The loads must never be held suspended for intervals even as short as a dinner break or the like.

A well organized coordination between persons engaged (commander in charge of hoisting, crew leader, slinger, crane operator, rigger, electrician) is one of the decisive factors ensuring a success in the job.

In handling heavy items commands are transmitted in the form of voice or sign signals. Voice commands are as follows: "UP" (lift the load), "DOWN" (lower the load), and "STOP" (cease the movement). A short-time movement is indicated by adding "A BIT" to the main command, such

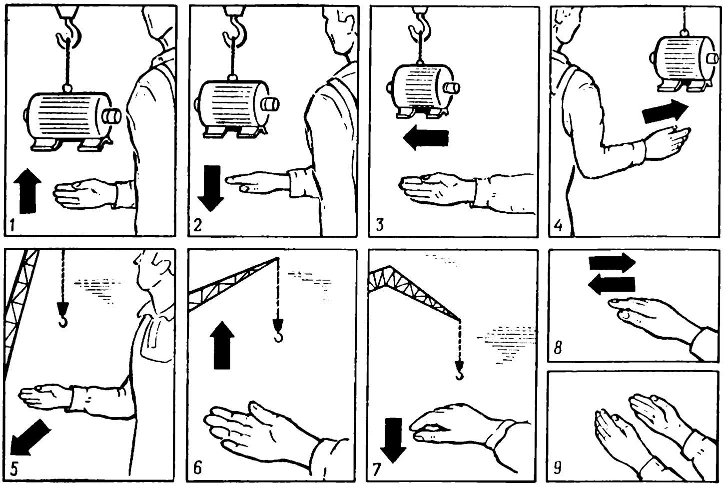


Fig. 9.3. Signs applied in handling heavy items
1 — lift the hook; *2* — lower the hook; *3* — shift the crane; *4* — shift the truck; *5* — turn the boom; *6* — lift the boom; *7* — lower the boom; *8* — stop; *9* — look out

as "A BIT UP". To indicate a slow and careful motion, "A LITTLE" shall be added to the main command. For instance, "A LITTLE DOWN". In order to ensure a clear understanding of commands, use can be made of megaphones, telephones, wire and wireless radio communication. As an alternative, commands can be given by signs, such as illustrated in Fig. 9.3.

CHAPTER TEN

Making Electrical Machines Ready for Installation

10.1. Make-up and Study of Technical Documents. Progress Plan

Pending installation, it will be essential to thoroughly make the site and equipment ready for use so as to ensure good quality of installation and to cut down the time required for this work. A negligence in preparatory work will cause considerable waste of time and labour for remedying an operation already done because of poor quality of accessories used in the job, dead time from lack of mechanisms, tools, rigging outfit, etc. That is why, the installation procedure in the case of large and medium-size electrical machines includes two stages, *viz.* a preparatory stage and an installation procedure.

Preparatory jobs are started from making up and studying the technical documents which include documents handed over by the User and those worked out by the installation contractor.

Documents handed over by the User comprise Manufacturer's documents (machine certificate, installation and maintenance instructions, reference drawings, parts lists and shipping specifications, assembly instructions (for machines delivered in a disassembled condition)), as well as working drawings tailored by the Designer to the installation site conditions.

All the technical documents supplied to the installation contractor by the User shall be certified with a stamp bearing the inscription "Authorized for use" and signed by the official in charge.

The scope and contents of *documents compiled by the installation contractor* depend on the power output and size of electrical machines to be installed. In the case of large electrical machines the installation contractor usually draws up a progress plan (PP) which is referred to as an

installation and wiring progress plan (IPP) by installation organizations dealing with electrical equipment. In the case of medium-size machines an instruction sheet will be quite sufficient.

The first documents to be studied are the machine certificate, technical description, installation and maintenance instructions. The latter are furnished complete as standard set of documents supplied by the Manufacturer together with the machine and placed in one of enclosed packages.

The certificate for the machine contains its basic specifications, *viz.* machine type, power output, maximum torque (for motors), date of manufacture, manufacturing plant, etc.

The technical description, installation and maintenance instructions contain brief information on the machine purpose, basic specifications, mechanical design, list of special tools and accessories supplied as standard equipment by the Manufacturer (such as, a wrench for adjusting the bolts of the rotor end plates pressing the field coils to the pole shoes, screws for holding down the rotor end plates, a wrench for compressing the stator core through the puller bolts of risers, a wrench for tightening the nuts locking these bolts, etc.), data on marking the electrical machine parts, recommendations on storage, preservation treatment and removal of preservative materials, disassembly and reassembly instructions, brief instructions for installation, wiring and preparation for operation, list of parameters to be checked, a trouble-shooting chart, safety precautions.

The technical description, installation and maintenance instructions include a number of drawings, such as a general arrangement drawing, a brush bedding diagram, a diagram showing how to measure brush pressure on the commutator or slip rings, a diagram showing how to detect insulation fault in bearings, a drawing of the stator puller arrangement, as well as other drawings illustrating a machine of particular size and application.

After that parts lists, delivery lists, shipping specifications, and factory assembly drawings shall be thoroughly studied. If the machines are supplied from the Manufacturer disassembled, the instruction on their assembling is studied. For the final procedure, the personnel engaged in the installation work shall familiarize themselves with

the installation and wiring progress plan (IPP) or the instruction sheet for electrical machine installation.

The IPP for large electrical machines shall include brief description of the installation site and associated equipment, technical characteristics of the equipment to be mounted, list of amendments and supplements to the design, table of technical and economical characteristics (size, cost, labour consumption), calender or progress schedule, installation procedure, including sequence of separate operations, freight traffic volume, list of hoisting and haulage facilities, tools, fixtures, basic and auxiliary materials to be used in the job, manpower sheet stating the qualification and number of workers required, safety precautions drawn up for the particular equipment and site. The IPP shall give considerations on the possibility of carrying out certain operations in parallel. The IPP is meant as a guide showing how to properly organize the work, to efficiently utilize the manpower, to prepare all necessary materials and facilities, how to place an order, etc.

The instruction sheet shall give only brief information to the personnel on technical characteristics of machines to be mounted, installation procedure to be used (including the description of separate operations), list of hoisting and haulage facilities, tools, fixtures, basic and auxiliary materials to be required, and safety precautions.

The installation and wiring progress plan and the instruction sheet are usually drawn up by the preparatory work teams (or groups of designers and estimators) of installation boards with due account for Manufacturer's instructions, technical characteristics of machines to be mounted, conditions in which they are dispatched (assembled or disassembled), haulage and hoisting facilities available, premises for the machines to be mounted, etc.

10.2. Scope and Contents of Preparatory Work

In addition to making up and studying the technical documents, introducing the mounting personnel to the technical characteristics and application of every machine to be installed and to other data it will be necessary to do the following in the course of preparatory work:

determine methods of fastening the electrical machines to foundations, methods of coupling the shafts of different machines to each other or to associated mechanisms with reference to mounting drawings supplied by the Manufacturer or to other technical documents;

note the bench marks (according to mounting drawings) for separately installed machines or sets and the main axes of shafts of driven mechanisms (for drive motors);

study the construction of bed plates and check the leading dimensions of foundations taking into account the bench marks; in checking the height of foundations it shall be borne in mind that the total thickness of pads and shims inserted under the bed plates is not to exceed 100 mm nor is it to be lower than 50 mm and that not more than five pads and shims shall be contained in each stack (including thin shims used for a final levelling);

give the Builders instructions for eliminating defects found in checking the leading dimensions of foundations;

determine the number and size of pads and shims for every electrical machine (according to Manufacturer's data), placing an order for pads and shims;

check for foundation bolts and their dimensions to comply with mounting drawings; inform the User on deviations found and draw up sketches for the manufacture of new bolts having desired dimensions;

determine the number of half-couplings to be required and make sure that they are available at User's store and that their dimensions comply with reference drawings; check shall be made, in particular, of the dimensions of half-coupling hub bores for compliance with those of the shaft journals to receive these half-couplings. If the fitting dimensions of bores do not comply with the dimensions of the shaft journals, the User shall be informed in a written form;

examine hoisting and haulage facilities, fixtures, ropes, slings, and mounting tools for condition and for missing parts and place orders for the latter;

together with the User's official, select the site for unloading and preparing the machines dispatched for installation, equip this site with all required rigging fixtures and accessories (sleepers, wooden and metal trestles and gant-

ries) as well as materials for covering the machine parts (canvas, tar paper, rubberoid, wrapping paper, etc.);

prepare containers and materials for flushing the machine parts, such as wrapping rags, kerosene, petrol, ethyl alcohol, xylene, as well as corrosion-preventive materials (gun grease, petroleum jelly, etc.);

equip the installation site with benches and lockers with drawers for keeping metal goods and small items;

together with the User and main Contractor, draw up a schedule of delivery of electrical machines and their parts to the installation site.

10.3. Inspection of Electrical Machines

The scope of inspection of electrical machines shall be determined depending on the condition of their delivery (assembled or disassembled), as well as on the conditions of their transportation and storage. If there is any doubt about transportation or storage conditions of machines delivered by the Manufacturer fully assembled, such machines shall not be disassembled on site and their inspection shall be reduced to the following steps:

external examination of machines for condition;

examination of winding leads, brush gear, bearings, commutator or slip rings, oil gauges, etc.;

flushing of sleeve bearings, checking of packing arrangements and their lubrication;

opening of antifriction bearings and check for the amount of bearing grease;

measurement of clearances between the bearing hub and the shaft journal by means of a feeler gauge (at easy-to-get-at places);

insulation resistance check of stator and rotor windings by means of a megger;

checking of the rotor for easy rotation when turned by hand. (It shall be borne in mind that the rotor fan must not brush against the end-shield caps.);

blowing-down of the machine windings and other parts with clean dry air to remove dust;

elimination of minor defects detected in the course of inspection.

More complicated repairs shall be made by the User.

Particular attention shall be focussed on antifriction bearings of machines dispatched in an assembled condition.

These bearings serve in transit as supports for the rotor with the result that at certain places they are cold-hardened (see Chapter Two).

This so-called "Brinell hardening" effect may cause failure of the machine in service. In order to prevent this fault, electrical machines with antifriction bearings dispatched in an assembled condition over a distance exceeding 1000 km are vibration mounted on transportation facilities and arranged across the direction of motion.

Some Manufacturers use, in addition, ring retainers placed in oil-control grooves of the rotor shaft and bolted to the bearing housing.

If there is any doubt about normal conditions of transportation and storage of machines delivered to the installation site assembled and dirt or damage may be suspected, a special report shall be drawn up by the officials of User and Contractors stating the necessity and amount of disassembly of the machine (see Appendix 2). This work shall be entrusted to the mounting contractor on special order. Such machines shall be first disassembled (fully or partially, according to the report) and only then inspected.

Disassembly and reassembly of electrical machines delivered in an assembled condition shall be carried out in full compliance with the Manufacturer's instructions. For instance, to fully disassemble a synchronous motor, the following procedures are envisaged by the Manufacturer's instructions:

check all the parts and assemblies for identification marking intended to correctly reassemble the machine;

disconnect oil pipes at the bearing split joints;

wrap the slip rings in pressboard to prevent accidental damage and remove the brushes and brush holders;

take the brush rocker off the bed plate;

separate the split joints one after the other and remove the end shield with packings and the baffle plates;

remove the side cover plates arranged at the feet and the lifting bolts;

separate the stator from the bed plate;

fit a pressboard spacer, 3 or 4 mm thick, in the air gap between the stator and rotor, so as to fully cover the stator;

remove the bearing caps and the upper halves of the bearing shells;

move the rotor up through 5-7 mm (for the arrangement intended to lift the rotor to a small height refer to Chapter Sixteen);

fit additional pressboard spacers in the air gap at the stator bottom. The spacers shall be as long as the stator and thick enough to prevent the rotor shaft from touching the bearing shells as the rotor is moved down;

push the lower halves of the bearing shells along the shaft journals, set them in the upper position, pull the oil slingers and remove the halves of the bearing shells from the journals;

fit additional pressboard spacers, 5 or 6 mm thick and as long as the stator, in the air gap at the top of the stator;

pull the rotor out of the stator (the rotor pulling arrangements are described in Chapter Eleven).

When only a partial disassembly is required, the following operations shall be carried out:

disconnect all the split joints one after the other and remove the end shields with gaskets and the baffle plates;

remove the side cover plates of the stator mounted at the feet and separate the stator from the bed plate;

mount four stator lifting arrangements (rollers) in the openings of the feet;

mount two stator pulling and lifting arrangements (Fig. 10.1) on the bed plate and secure them thereon;

lift the stator by means of the rollers and take out the pads and shims placed between the stator feet and the bed plate;

shift the stator by means of the arrangements shown in Fig. 10.1 taking care that its seizure against the rotor be prevented. In the action, fasteners *2* on rods *1* shall be rearranged, as required;

release the puller bolts on the rollers and move the stator down onto the bed plate having placed pads and shims under its feet, if necessary.

An almost similar procedure shall be followed for dismantling induction motors and direct-current machines. After the

machine is disassembled, the stator and the rotor shall be subjected to an inspection including the following checks:

tightness of wedges holding the coil sides in the stator slots;

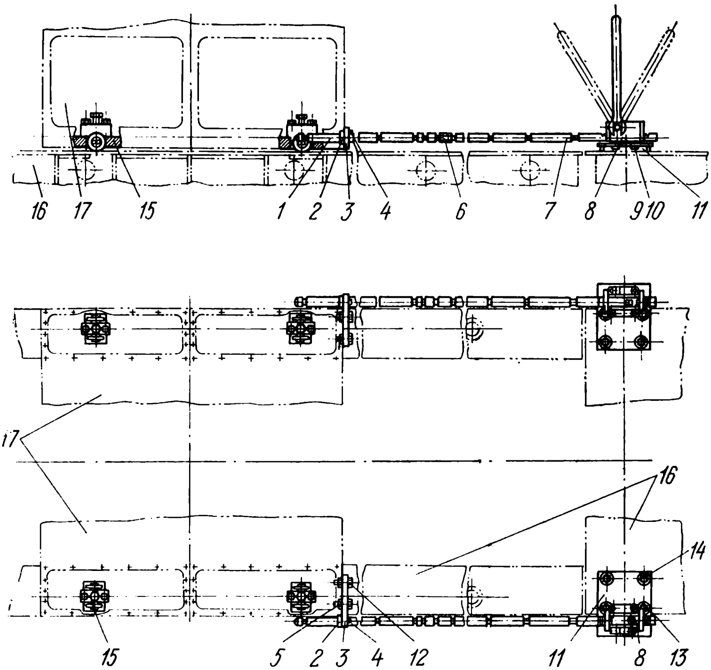


Fig. 10.1. Stator pulling and lifting arrangement

1 — rod; *2* — fastener; *3* — strap; *4* — bolt; *5* — nut; *6* — union nut; *7* — rod; *8* — stator puller; *9* and *10* — gaskets; *11* — support; *12*, *13*, and *14* — bolts; *15* — stator lifter; *16* — bed plate; *17* — stator

condition of insulating coating on the end windings and of mica troughs at the points where the coil sides leave the stator slots;

condition of stator and rotor iron stacks (there shall be no dents, nicks, or pits due to rust on the slot teeth);

condition of bearing pedestals and shells;

condition of commutator (in case of dc machines) and soldered joints at the commutator risers and at connecting buses between the armature coils and the commutator bars;

insulation resistance of windings (including the field and compensating winding in case of dc machines) and insulated parts of the brush gear.

Inspection of bearing pedestals involves checking of the seating surfaces of bearing shells for tight fitting, removal of rust, nicks, and scratches. Particular attention shall be paid to the working surfaces of white metal (in the bearing shell bore) which must be free from scratches, nicks, and dents. If such defects are detected, they shall be eliminated and the white metal surface shall be scraped to fit the shaft journal. Besides, the bearing pedestal interior shall be examined for the condition of paint coating and for leakage through the pedestals. If leakage is detected, the cracks shall be welded up and all the joints at the bearing caps and oil traps shall be checked for tightness.

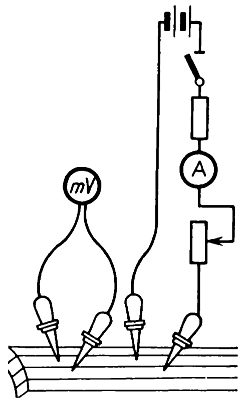


Fig. 10.2. Circuit arrangement for checking the condition of soldered joints at commutator risers and turn-to-turn fault in windings

The split joints are to be checked by means of a feeler gauge, 0.05 to 0.1 mm thick. With the bolts on the bearing caps turned out the feeler gauge shall pass nowhere through the joint. The clearance between the bearing cap and the upper bearing must be within the range of 0.05 to 0.1 mm. The cap must not exert any pressure on the shells.

Soldered joints at the commutator risers are to be checked by measuring the voltage drop across the commutator bars at a current of 5 to 10 A through the armature windings. Fig. 10.2 illustrates the circuit arrangement for checking the soldered joints at the commutator risers. It shall be borne in mind that measurements are to be made between two adjacent commutator bars in the case of a single re-

entrant winding and at one commutator bar when a double re-entrant winding is used.

A fully charged storage battery providing for a stabilized voltage of 4 to 10 V shall be used as a power source for these measurements. Current is to be applied to the commutator bars through special probes and a rheostat shall be employed to maintain this current at a constant level.

The quality of soldered joints at the commutator bars is checked by a difference in voltage drops (or in resistance found by the Ohm's law) which shall not exceed 10 per cent for serial-production machine. A difference of 20 to 30 per cent may be allowed for armatures with equalizing connections. Soldered joints shall be considered as defective if the voltage drop (resistance) is higher than the above-specified value.

In electrical machine installation and wiring practice there were cases of a ring fire appearing on the commutators at the first excitation and loading of dc machines as a result of shorted-out buses connecting the compensating winding bars at the end portions. The amount of trouble caused by the ring fire depends on the point of short-circuit on the compensating winding. That is why, a particular attention shall be concentrated on the slots between buses when inspecting the dc machines incorporating compensating windings.

Faults detected during inspection shall be eliminated by the mounting personnel or by the User with the aid of specialists from the manufacturing plant, if it is necessary.

When machines dispatched in a disassembled condition are to be urgently handed over for installation, the machine parts shall be thoroughly cleaned of dust, dirt and slushing grease.

In order to remove slushing grease from small items, the latter shall be dipped in a solvent for 25-30 minutes and then wiped dry with a clean rag.

Anti-corrosive varnish and paint coatings shall be removed from large parts by means of a solvent (white alcohol xylene). Small items shall be dipped in a solvent for 25-30 minutes.

10.4. Marking-out of Axes, Checking and Acceptance of Foundations

Checking of concrete foundations for condition shall be started by external examination, sounding-out by a hammer and testing with a chiesel in the horizontal and vertical directions. A solid and robust concrete is recognized by a clear (and not dull or rattling) sound and, when sounded out, it shall not chop up or crumble.

If there is any doubt about the proper condition of the foundation, builder experts shall be invited for its examination and the appropriate report drawn up stating whether the foundation is suitable or unsuitable for the installation of electrical machines.

Checking of the foundation for compliance with the design is to be started from the determination of its position relative to the building and to the adjacent machines and accuracy of its dimensions with reference to the main axes. Thereupon, checks shall be made of the foundation height, sizes of recesses for the stators and ducts within the foundation, levelling of its upper surface, arrangement and condition of holes to receive anchor bolts.

In order to ensure the desired accuracy of installation of electrical machines and associated equipment, it will be necessary to lay out the main longitudinal and transverse centre lines as well as the bench marks on their foundations which shall be used as reference marks in erecting the equipment. The centre lines and the bench marks are to be arranged so as the machines to be mounted do not shield them.

For the time of installation the position of centre lines on the foundation is marked with a stretched steel wire, 0.3 to 0.5 mm in diameter, fixed above the machine so that it does not interfere with its installation. The stretched wire is to be supported by two holders illustrated in Fig. 10.3. The upright *5* carries a clamp *4* with two nuts *1* (a right-handed and a left-handed one) and a pin mounting a carrying roller *3* for the steel wire which is tensioned under the effect of a suspended counter-poise *6*. Two plum-bobs *9* are suspended on threads *8* from the wire *7* and the pointed ends of these plum-bobs are aligned with the points marked on

dies *10*. The tension of the stretched wire is adjusted by turning nuts *1* in the appropriate direction.

Figure 10.4 shows the marking-out of the main centre lines on the foundation. The first thing to do is to determine the main longitudinal axis. To this end, one end of the wire is fixed on one of the holders and the other end is slipped over the carrying roller of the other holder and tensioned by means of the counter-poise *6* so as to take up the sag (see Fig. 10.3).

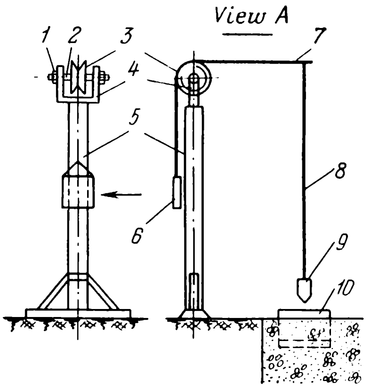


Fig. 10.3. Wire holder with stretched wire and plum-bob

1 — adjustable nut; *2*—pin; *3* — carrying roller; *4* — clamp; *5* — upright; *6* — counter-poise; *7* — string; *8* — plum-bob thread; *9*— plum-bob; *10* — die

The stretched wire is to be subjected to a hanging test before use. The 0.3 mm dia wire is to be tensioned by a counter-poise having a mass of 7 kg and the 0.5 mm dia wire, by that having a mass of 20 kg.

The stretched wire is to be checked for correct setting by the middle points between the centres of holes for anchor bolts arranged on either side of the longitudinal centre line.

Then vertical plum-bobs are to be suspended from the longitudinal stretched wire and the longitudinal centre line is to be marked on the surface of the foundation with coloured chalk, a punch, or a chisel. After the longitudinal wire is reliably fixed, the transverse centre line shall be laid out.

The transverse centre line shall be strictly perpendicular to the longitudinal centre line. To check this condition, two different sections OA and OB of an arbitrary length are to be measured off from point O of intersection of the wires (Fig. 10.4) and points A and B are transferred to the foundation surface (points A_1 and B_1). Then point C is to be marked on the longitudinal centre line drawn on the foundation. Distances A_1C and B_1C will be equal if the centre lines are perpendicular.

The first step after the fixation of the longitudinal and transverse stretched wires is to thoroughly check the size and arrangement of holes for anchor bolts and the recesses for their plates. To this end, plum-bobs are to be dropped at the centre of every hole down to the lower surface of the recess. The centres of other holes are to be determined by means of portable supports on which wires are tensioned

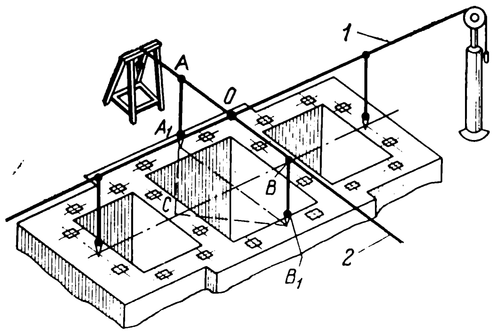


Fig. 10.4. Marking-out of main axes on the foundation
1 — main longitudinal axis; *2* — main transverse axis

to mark out auxiliary longitudinal and transverse centre lines of holes. Then it will be necessary to check the length, width, and depth of the holes. It shall be borne in mind that the length and width of the holes must be conservative. No projections are allowed inside the holes. The holes shall be strictly vertical so as to prevent misalignment of the anchor bolts.

Basic axial dimensions of the foundation and compliance of the latter with the design are to be checked against the main centre lines by taking measurements with a rule or a measuring reel. The height of the foundation is to be checked against the preset data of height by means of an alignment sight or a hydrostatic level.

The operating conditions of machines being installed are the decisive factor determining the required accuracy of their positioning on the foundations against the centre lines and data of height (bench marks), the most essential condition being whether a set of machines (such as a motor-

generator set) is installed separately or in line with adjacent machines (such as drives of breaking-down and finishing stands of a rolling mill).

The height of foundations intended for mounting electric motors coupled with other machines or mechanisms shall be checked with particular care. The upper surface of the foundation is to be examined for proper levelling by means of levels or an alignment sight.

When checking the recesses for anchor bolts in the foundation it shall be borne in mind that the dimensions of these recesses must be large enough for easy mounting of plates and the surface shall be even and horizontal throughout the entire fitting area of the plates.

The foundations may be accepted for mounting the electrical machines on condition that they are in full compliance with the design dimensions and the layout of embedded parts and holes. Permissible tolerances are as follows:

For longitudinal and transverse centre lines of foundations	20 mm
For basic plan dimensions	30 mm
For bench marks on foundation surface, less the height of grout	30 mm
For plan dimensions of holes	+20 mm
For plan dimensions of projections	—20 mm
For marks of projections in recesses and holes	—20 mm
For plan axes of anchor bolts	5 mm
For plan axes of embedded parts	10 mm
For marks of top faces of anchor bolts	+20 mm
For depth of anchor bolt holes	+50 mm

The plus (+) sign indicates tolerances for an increase in dimensions and the minus (—) sign shows tolerances for a decrease in dimensions or in height of marks. Unspecified deviations shall be stipulated in reference drawings.

The quality of the foundation concrete is of great importance. The mechanical strength of concrete is determined at the Builder's laboratory by test specimens made of the same material and at the same time as the foundation. The grade of concrete is specified in the design project.

As has been already stated, large electrical machines are to be levelled off in the course of installation by means of pads and shims. That is why, the Builders must build up the foundation to the required bench marks. After such a

procedure the foundation is to be accepted from the Builders according to a report warranting its suitability for the installation of electrical machines.

In the event of foundations having a reduced height and the motor-generator sets weighing up to 20 tons, the bed plates are to be mounted on pads made of I-section beams

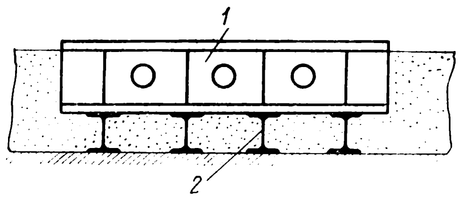


Fig. 10.5. Mounting the bed plates on I-beam pads
1 — bed plate; *2* — pad

and not on usual pads, the height of the pad being not over 160 mm (Fig. 10.5).

All faults detected in the course of inspection of the foundation shall be eliminated before mounting the electrical machines.

The foundation check results are to be entered in a report certifying the condition of the foundation (see the Appendix, Form No. 5) and containing a statement of its suitability for mounting the electrical machine.

The foundation condition report shall be supplemented with a service log for the foundation containing the following data:

(a) design and actual marks on the surface as well as actual basic dimensions of the foundation;

(b) design and actual lay-out dimensions and markings of anchor bolts, embedded parts, and holes for anchor bolts;

(c) lay-out of the foundation main centre lines;

(d) arrangement and reference points of bench marks embedded in the foundation;

(e) arrangement of metal strips embedded in the foundation or secured to the building and arrangement of clamps fixing the stretched wires which indicate the main centre lines of the foundation.

CHAPTER ELEVEN

Installation of Electrical Machines Coming in a Disassembled Condition

11.1. Sequence of Operations

Large electrical machines incorporated in multimachine sets or separate electric motors delivered in a disassembled condition are usually subjected to a pre-dispatch assembly at the manufacturing plant.

Hence, most operations relating to the preparation of the machines for installation are carried out by the Manufacturer. For instance, the fitting surfaces of the bed plates of such machines have tapped holes for mounting and fastening the bearing pedestals, stators, and protective casings; the Manufacturer furnishes these machines complete with appropriately selected and finished metal pads, insulating gaskets, bushes and washers for insulating test studs and bolts securing the bearing pedestals; separate parts of machines, such as protective casings, packing joints, etc., are fitted to their counter-parts. Thus, the work to be done on site is greatly reduced.

The electrical machines dispatched in a disassembled condition are to be mounted in a definite sequence, the procedure being as follows:

mount and level off the bed plate and the bearing pedestals;

mount the machine rotor and roughly align its shaft with that of the associated machine already installed;

mount the stator. To this end, remove the rotor and one of the bearing pedestals, introduce the rotor into the stator, and re-install the bearing pedestal;

finally align the machines;

check the stator for proper mounting;

install the remaining parts of the machine.

Such a sequence envisaging the rotor installation and alignment of its shaft before the stator mounting facilitates

the final alignment of the machines involving the displacement of the bed plate.

In mounting less heavy machines the stator can be installed before the rotor and the machines are to be aligned after that. The same procedure shall be used in mounting the machines having a single pedestal bearing as well as in mounting medium-size drive motors.

The rotors of large slow-speed ac machines and the flywheels are delivered removed from the shafts so as to facilitate their transportation. These rotors and flywheels are to be fitted on the shafts in situ.

The stators of large slow-speed ac machines and those of large dc machines are often split horizontally in order to meet transport limitations. These stators shall be assembled and the ac winding coils mounted at the split joints on the site of installation after the installation and rough alignment of the rotor.

This chapter deals only with the installation of bed plates, bearing pedestals, stators, and rotors. Alignment of shafts, fitting of bearing shells and assembling of bearings, wiring, and trial start of the machines will be described hereunder in the respective chapters.

The scope of work to be done in the installation of electrical machines coming in a disassembled condition depends on the type of machine; especially this concerns the bed plates. The installation and levelling-off technique of the latter is different for motor-generator sets and for drive motors.

11.2. Installation and Levelling-off of Bed Plates for Motor-Generator Sets

The bed plates of large and medium-size machines incorporated in motor-generator sets can be made in one piece, sectionalized, or separate for each machine, which depends on the machine size. The bed plates are manufactured of thick sheet steel or of large-section channel bars and beams.

The bed plates are secured to the foundation by means of anchor bolts. As has already been mentioned, hook-type bolts (see Fig. 1.8) are used for comparatively small machines. The length of such a bolt for machines operating in a

light duty shall make up at least 20 diameters of the bolt and that for machines running in a heavy duty is to make up as many as 40 diameters of the bolt (up to 2 m).

The bed plates of large machines are secured to the foundation by means of anchor bolts and anchor plates (see Fig. 1.9). The bolts are available of sizes as large as 90 × × 3500 mm and of a mass as heavy as 175 kg. Hoisting facilities are required for their mounting.

When hook-type bolts are used and holes to receive them are made blind, the bolts shall be installed in the holes before the bed plates are mounted on the foundation.

The bed plates shall be set on metal pads on the foundation. The number of pads, their dimensions and location

Table 11.1

Pads for Bed Plates

Material and shape of pad	Dimensions, mm		
	height	width	length
Cast-iron plates or bars (grade C-100 or C-12-26 cast iron)	50-100	100-120	Bed plate width + (50-100)
Strip or sheet steel	5-50	50-120	Same
Strip steel for adjustment pads	0.5-4	50-120	Same
Opposing wedges	Dimensions and bevel angles are to be determined on site		

are specified by the Manufacturer. Table 11.1 gives recommendations on the dimensions of pads for bed plates.

Adjustable pads illustrated in Fig. 11.1 have shown good results in practice. The pad base *1* is a wedge having a trough and a slot to receive the screw shoulder. The cover *2* is provided with wedge slides and a boss inbetween which has a thread to receive the screw. Turning the screw *3* with a wrench makes the boss rest against the slot in the base thereby pulling the cover and raising the bed plate. When adjustable pads are used, they shall be replaced with permanent pads of the required thickness before grouting in.

The bed plate is levelled off and adjusted in height by selecting the pad thickness. Wedge jacks may be likewise used for the purpose.

In selecting the pads it shall be borne in mind that their number per stack must be as small as possible and not

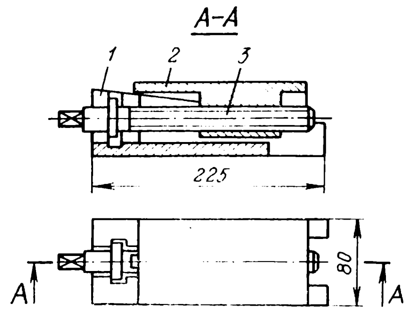


Fig. 11.1. Adjustable pad

greater than five, including thin shims used for final adjustment. After the machine is levelled off, adjustable pads shall be replaced by permanent ones.

The bed plates shall be adjusted in height so as to provide a clearance of at least 50 mm between the plate and the foundation surface and a space sufficient for inserting shims, 5 to 7 mm thick, under the bearing pedestals and stator feet, whenever necessary.

A new technique has been recently developed by experiment for the installation of bed plates of motor-generator sets rated up to 3500 kW and 3000 r/min with a smaller number of pads and shims.

The experimental work has been based on the fact that with the old installation technique the concrete grout practically takes the external load transferred from the machine to the foundation and does not serve as an auxiliary part.

All the electrical machines installed in compliance with the new technique operate normally though the number of pads has been reduced by 25 to 30 per cent.

As adequate results were obtained during experimental work and in operation, the electrical machine installation instructions issued since 1970 have specified a smaller num-

ber of pads to be inserted under the bed plates of electrical machines.

According to these specifications, the pads for bed plates having bottom feet shall be inserted only at points of lumped loads, i.e. at bearing pedestals, frame feet, and on both sides of anchor bolts. For bed plates having no bottom, feet pads of strip steel, 5 to 20 mm thick, shall be placed under the ribs located in close proximity to the anchor bolts, under the bearing pedestals, frame feet, and under the remaining ribs so that the axes of pads were spaced 1000 mm apart. Due to such a location the number of pads may be reduced by 30 per cent.

The foundation surface to mount the bed plate shall be thoroughly cleaned of built-up and chipped concrete, dust and dirt by blowing it down with compressed air. At the points of installation of pads the foundation surface shall be thoroughly levelled off and fitted to a metal plate so that the slope does not exceed 0.2 mm per 1 metre. It will be a good practice to use special-purpose portable tools, such as a pneumatic bush hammer and an electric planetary mill illustrated in Fig. 6.5 for cutting off the concrete and levelling the location surfaces on the foundation. The remaining surfaces shall be roughened with a pneumatic hammer or a chisel to obtain better adhesion between the foundation body and the grout. After that the foundation surface shall be cleaned off again and flushed in water whereupon pads shall be installed at their respective places.

Surfaces on the bed plate to be grouted in concrete shall be cleaned of protective paint and wiped dry with rags. It shall be borne in mind that oil spots on the surface may cause exfoliation of the concrete grout.

The bed plates are to be mounted on the foundation with the aid of a crane. A bed plate (or several ones, when the bed plate is a sectionalized structure) delivered to the foundation is to be mounted on pads so that the latter project 25-30 mm on either side from under the bed plate. The anchor bolts are to be dropped in the foundation holes through the holes in the bed plate; then plates and nuts shall be installed on them. Heavy bolts are to be dropped by means of the same crane with the aid of a special nut having clips for slings welded at its edges.

The anchor bolts shall be thoroughly examined and cleaned before installation, their sizes are to be checked for compliance with the depth of holes in the foundation, height of the bed plate, anchor plates, and pads. The bed plate, when moved down, shall be aligned against the main longitudinal and transverse centre lines marked on the foundation during its acceptance; the centre lines of holes for anchor bolts in the bed plate shall be checked for alignment with those in the foundations.

The bed plate mounted on pads is to be set down by turning in the anchor bolts. In the action, the pads under the bed plate shall be set down by means of a hammer. After that the nuts shall be released and the bed plate checked for levelling-off.

To this end, the stretched wires indicating the main longitudinal and transverse centre lines shall be set in position and the bed plate position is to be checked against installation drawings. Before doing this, the bed plate shall be roughly set in the horizontal position and then levelled off against the longitudinal and transverse centre lines and adjusted in the horizontal plane as is shown in Fig. 11.2. The bed plate is to be adjusted in position against the main centre lines by means of plum-bobs fitted on the above-mentioned stretched wires. The plum-bombs are dropped onto the longitudinal and transverse centre lines drawn on the bed plate.

A hydrostatic level shall be used for a rough levelling-off of the bed plate. In the action, care shall be taken to prevent air bubbles from forming in the fluid within the tube of the level, otherwise the fluid level in the communicating cups may be different.

A fine levelling of the bed plate shall be carried out by means of a shaft level gauge mounted on shaped surfaces of the bed plate or on the mounting rule. Use can also be made of a gradienter for levelling off the bed plates.

Installation of the bed plates may be ceased as soon as their surfaces are levelled off in respect to the main centre lines and in height accurate to two or three scale divisions of the level having a scale increment of 0.1 mm per 1 metre.

In the course of levelling-off the bed plate is to be raised by means of a crane or jacks.

In exceptional cases, when it happens that the holes for anchor bolts in the foundation are improperly spaced and the bed plates cannot be accurately adjusted against the

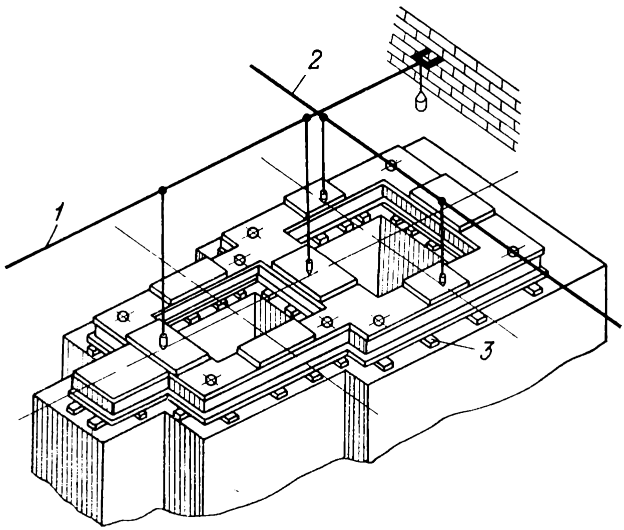


Fig. 11.2. Installation of bed plate
1 — main longitudinal axis; 2 — main transverse axis; 3 — pad

predetermined axial directions and to widen these holes presents a great difficulty, it may be allowed to bend the anchor bolts as is illustrated in Fig. 11.3 so as to provide for

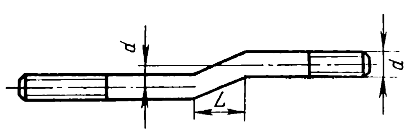


Fig. 11. Anchor bolt bending to allow for the displacement of bed plate

a locational clearance to displace the bed plate. With such a bend the centre line of the bolt shall be shifted by not more than the diameter d , and the length L shall make up at least 8 or 10 diameters of the bolt. As an alternative and

upon agreement with the Manufacturer, it may be allowed to widen the hole in the bed plate by flame boring or to flame-drill a new hole at the desired point. It is not recommended to make new holes in the foundation as this may cause serious damage.

The anchor bolts as well as those fastening separate sections of the bed plates shall be turned in uniformly. To this end, the diagonally opposite bolts shall be turned in simultaneously and with a sufficient force applied to them.

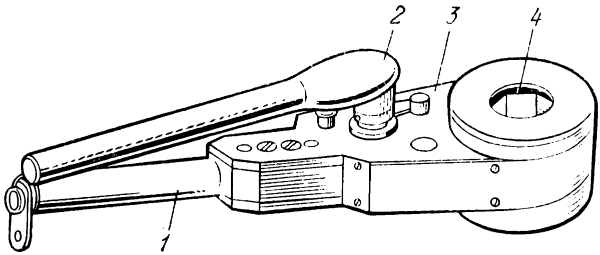


Fig. 11.4. Tool for tightening the nuts on anchor bolts

When turning the bolts manually, a gas pipe shall be fitted on the wrench handle, this pipe being three or four times as long as the handle. It will be a good practice to use a special arrangement illustrated in Fig. 11.4 for tightening the anchor bolts. The arrangement consists of a shroud *3*, a pivoted handle *2* and a fixed grip *1*. The shroud accommodates a toothed crown *4* having a seat to receive the nut, a toothed plunger, a connecting rod, and a cam carrying a square at the end. To turn in the nut, the handle shall be moved in both directions. For the complete tightening of the nut it will be necessary to turn the detachable handle mounted on the square at the end of the shaft.

The arrangement can be driven by the type И-28А electric drill which is to be mounted on the shaft of the arrangement through an adapter fitted with a square hole on one end. This arrangement is suitable for turning in nuts having a thread of M56. The arrangement mass is 10 kg.

After the anchor bolts are fully tightened up the bed plate shall be again checked for levelling and correct positioning

relative to the centre lines. Thereupon, the pads and shims of every pile placed under the bed plate shall be welded together.

Given below are steps to be taken for mounting separate parts of motor-generator sets. Recommendations on mounting the bed plates and on the installation and wiring technique for drive motors dispatched in a disassembled condition will be found at the end of the chapter.

11.3. Installation and Levelling-off of Bearing Pedestals

The bearing pedestals shall be mounted on the bed plate on adjusting metal shims, 5-7 mm thick.

Insulating shims, 2-5 mm thick, shall be fitted under one or two of the pedestals, as is specified in the Manufacturer's installation drawings.

Metal shims shall be thoroughly straightened and cleaned off with a file to remove burrs and other defects liable to cause misalignment of pedestals.

Metal shims shall project from under the pedestal by at least 5 mm along the entire contour and insulating shims shall jut by 5-10 mm.

Insulating shims are usually furnished complete with the machine by the Manufacturer. These shims are required to prevent shaft currents from flowing through the bearings, which otherwise may cause deterioration of white metal and attack the shaft journals. Shaft currents usually appear due to an unbalanced magnetic field of the machine causing a pulsatory magnetic flux which cuts the circuit shorted via the shaft, bearing, bed plate, and shaft, with the result that heavy currents may appear. The insulating shims are meant to open this circuit.

The Manufacturer's installation drawings also specify the insulation of bolts fastening the bearing pedestals to the bed plate as well as tapered check pins and flanged joints of the oil pipe.

Bolts are to be insulated with 2-mm thick bakelite sleeves and taper pins must be covered with insulating pressboard sleeves.

The diameter of fabric-base laminate washers on the bolts and check pins shall be 10 mm larger than that of metal washers placed under the nuts. The bolts and check pins shall be insulated only in the pedestals set on insulating shims.

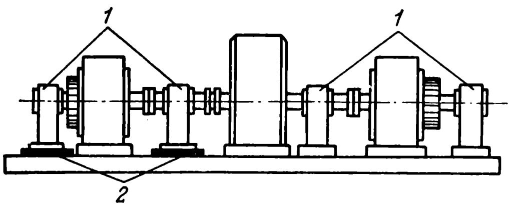


Fig. 11.5. Location of insulating gaskets under the pedestals of motor generator sets with four bearings

1—bearings; 2 - insulating gaskets

Figure 11.5 shows in a thick line insulating shims placed under the bearing pedestals of a motor-generator set fitted with four bearings. Fig. 11.6 illustrates the insulation of

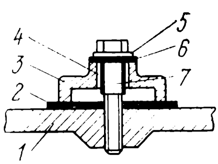


Fig. 11.6. Bearing pedestal bolt insulation

1 — bed plate; 2 — paper-base insulating gasket under the bearing pedestal; 3 — bearing pedestal base; 4 — bakelite tube; 5 — metal washer; 6 — fabric-base laminate insulating washer; 7 — pedestal-to-bed plate fastening bolt

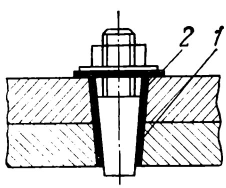


Fig. 11.7. Check pin insulation

1 — tapered pressboard sleeve; 2 — fabric-base laminate washer

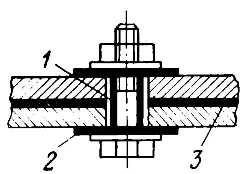


Fig. 11.8. Oil pipe flange insulation

1 — insulating tube; 2 — insulating washer; 3 — insulating ring

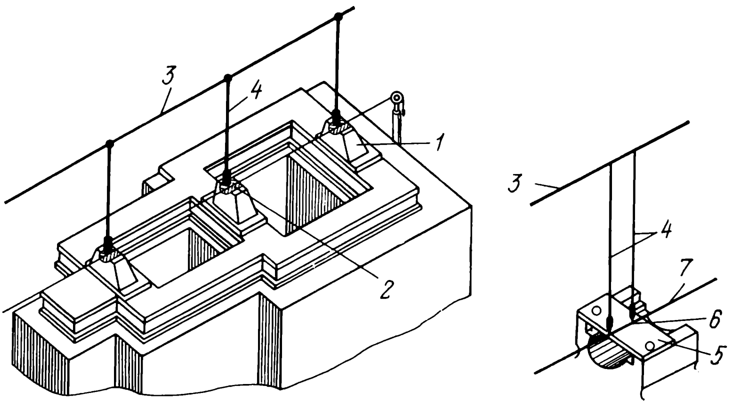
the bearing pedestal bolts, Fig. 11.7, the insulation of the check pin, and Fig. 11.8, that of the oil pipe flanged joint.

The bearing pedestal-to-bed plate insulation resistance shall be measured with a 1000-V megger before mounting the shafts in the bearings. This insulation resistance shall

be at least 0.5 megohm* with pedestal fastening bolts tightened up.

The results of measurements are to be entered in an installation report or certificate for the machine.

After the inspection of bearings and preparation of metal and insulating shims all these items are fitted in their res-



(a) (b)

Fig. 11.9. Adjustment of bearing pedestals

pective places and bearing pedestals *1* (Fig. 11.9*a*) are set in position by means of a crane. Then the bearing caps are taken off, the lower shells are removed and wooden bars *2* are fitted in their place. These bars are used to mark on them the centre lines of the bearings. Plum-bobs *4* are dropped from the main longitudinal stretched wire *3* to adjust the position of the bearing pedestals relative to the longitudinal centre line (Fig. 11.9*a*).

The bearing pedestals may be mounted as is shown in Fig. 11.9*b* against the stretched wire *3* indicating the position of the shaft centre line. To this end, metal strips *5*, about 100 mm wide, bearing notches *6*, are to be fixed at the

* An insulation resistance of 0.5 megohm is admitted by Instructions for Installation of Electrical Machines.

An insulation resistance of at least 1 megohm is specified for synchronous generators and synchronous condensers only.

split joints of the bearings. The bearing pedestals are to be adjusted by means of plum-bobs *4* whose pointed tips shall lie on the bearing centre lines *7*. In order to adjust the pedestals against the longitudinal and transverse centre lines, two plum-bobs shall be dropped on every line. Such an adjustment shall be made for all the bearing pedestals.

The bearing pedestals shall be checked for accurate mounting by measuring the clearance between the bore and the stretched wire with the aid of an inside micrometer. This check can be made by means of an electric circuit (Fig. 11.10)

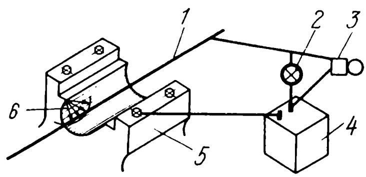


Fig. 11.10. Circuit arrangement for the adjustment of bearing pedestals
1 — stretched wire insulated at points of attachment; *2* — lamp; *3* — bell; *4* — 4- or 6-V storage cell; *5* — bearing pedestal; *6* — internal micrometer

in order to provide a higher accuracy than the human eye can afford. A 4 to 6 V storage battery or a 6 to 12 V transformer can be used as a power source. The stretched wire shall be insulated at the fastening points. One of the power source terminals is to be connected to the wire via a lamp or a bell. The moment the inside micrometer comes in contact with the stretched wire is indicated by the glowing lamp or the ringing bell.

The split joint surfaces of the bearings shall be checked for levelling-off by means of a level every time when mounting and adjusting the pedestals. When the bearing pedestals are mounted on separate bed plates, they shall be checked, in addition, for correct spacing against the installation drawing.

The bearing pedestals must be mounted with utmost accuracy. This is, however, a rough mounting and check pins shall not be installed. A fine setting of the bearing pedestals is made during the alignment of shafts (see Chapter Sixteen).

If the machines have been assembled by the Manufacturer, the bearing pedestals are to be mounted against the factory check pins. In such an event, metal and insulating shims supplied by the Manufacturer are to be installed in their respective places and the pedestals are carried to the bed plates by means of a crane or a hoist and installed in position against the check pins. Then the pedestal is to be checked against the bench mark and the split joint surfaces of the bearings are to be checked for levelling-off. If a necessity arises, the height of pedestals can be adjusted by changing the thickness and number of metal shims.

If the machine has not passed an assembly procedure at the manufacturing plant and the bed plate has no holes for fastening the pedestals, the latter are to be mounted as described above and holes for fastening bolts are to be drilled in the bed plate.

Holes for check pins are usually drilled after an on-load running-in or, in the event of a broken shaft line, after a trial start of the machine.

11.4. Pre-Installation Check of Stator and Rotor

The rotor and stator shall be examined just before the installation. To this end, the machine rotor or armature is to be mounted in its bearings or on specially made stacks of sleepers. The surfaces of the rotors and stators are to be wiped with dry rags, the windings are to be blown down with dry compressed air at a pressure of not over 2 kgf/cm^2, exfoliated paint is to be removed.

The rotor shaft shall be cleaned of slushing grease before examination.

In the course of examination the following shall be checked:

setting of wedges holding the coil sides in slots. The wedges shall be tightly set in slots and shall not protrude beyond the iron stack. When lightly tapped with a mallet, they shall not chatter (to be checked by hand). Protruding portions of wedges shall be filed off;

setting of wire bands holding the end windings in dc machines. The wire bands must not be loose nor must they jut above the rotor stack;

condition of insulating coating on the end windings and of mica troughs at the points where the coil sides enter the slots. The windings shall be free from external damage. Pits and other defects on the vanish coating are inadmissible;

condition of slot teeth which shall be free from traces of corrosion, dents, and nicks;

condition of commutators in dc machines, fixation of current leads of slip rings in the rotors of synchronous machines and induction motors, fixation of poles, interpole spacers and connections; besides, squirrel-cage rotor starting windings of synchronous motors shall be examined. Sometimes, when the machine is painted at the manufacturing plant, paint penetrates through a loose contacting joint at strips connecting the rotor bars. This may cause a ring fire during the machine starting. To avoid this trouble the bolted joints of the squirrel cage shall be thoroughly examined and reliably tightened up. If paint has penetrated into the joint, the machine shall be disassembled and thoroughly cleaned of paint;

condition of terminals and winding leads at the split stators;

connection of wire leads in ac machines in compliance with available supply voltage, *viz.* star or delta, shunt or series connection of winding leads;

internal connections of dc machines;

sequence of main and commutating poles in dc machines (see Chapter Nineteen). In addition to the correct sequence of its own polarity, the cumulatively compounded winding shall be wound in the same direction as the main pole coil while the differentially compounded winding shall be wound in the opposite direction;

condition of soldered and bolted joints; the soldered connections at the commutator risers shall be free from black spots, cavities, air bubbles, etc.;

insulation resistance of all the windings and other parts mounted on insulating gaskets, in troughs and bushes.

When examining dc machines with compensating windings a particular attention shall be concentrated on the

slits between buses connecting the butt ends of the compensating winding bars at the end portions. Small items, such as nuts, etc., accidentally getting into these slits may short out the buses with the result that as soon as excitation voltage is applied and a load is connected serious faults may appear in the commutator.

11.5. Fitting the Rotor onto the Shaft

The rotor is to be fitted onto the shaft just before installation in case it cannot be dispatched assembled with the shaft due to transport limitations. A negative allowance shall be provided between the shaft and the rotor hub.

In fitting the rotor onto the shaft it is essential to bear in mind the following factors:

difference between the rotor and shaft temperatures: the higher the temperature of the rotor relative to that of the shaft, the easier will be the procedure as the bore in the rotor hub will be larger;

deviations of the diameters of the shaft and rotor hub from the nominal values (within the tolerance limits);

condition of the shaft journal and rotor hub finished surfaces; rough surfaces are difficult to be mated;

force applied at fitting.

Prior to fitting the rotor onto the shaft, the hub surface and that on the shaft shall be thoroughly examined, cleaned of slushing grease and washed out in kerosene. Scratches and burrs are to be carefully removed with the aid of a sandpaper strip. The rotor is shrunk on the shaft while hot.

The interference fit shall ensure the required rigidity and, at the same time, must not cause excessive stresses in the hub metal. The amount of interference is specified by the Manufacturer. The expected interference can be checked on the basis of the following data obtained by experience.

The cold rotor hub diameter shall be 0.08 to 0.1 mm smaller than the diameter of the fitting portion of the shaft for every 100 mm of the shaft diameter. These data are in full compliance with standards used in mechanical engineering (see Table 8.3).

Prior to fitting the rotor on the shaft it will be necessary to measure the fitting dimensions of the hub bore and the shaft diameter as well as to check the hub bore and the shaft fitting portion for taper. The hub bore and the shaft fitting portion must be true to a cylindrical shape.

The hub bore is to be measured with an inside micrometer and the shaft diameter, with a micrometer snap gauge. Measurements shall be taken at not less than three points over the hub and shaft fitting lengths and, by all means, at two perpendicular surfaces. It will be good practice to check the inside micrometer readings by taking additional measurements at the end of the bore with precision callipers. The fitting operation may be started if the results of measurement are adequate. In the event of inadequate dimensions it will be necessary to apply to the Manufacturer.

The rotor can be mounted on the shaft by one of the two methods, *viz.* (a) the shaft is fixed vertically and limiting stops are placed nearby, and (b) the shaft is placed horizontally and the rotor is mounted from one side.

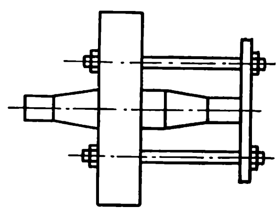


Fig. 11.11. Arrangement for mounting the rotor on the shaft

The (a) method is used in rare cases and with short shafts only. The rotor is to be mounted onto the shaft by means of a hydraulic jack or a hoisting rig consisting of two bolts and a lifting beam (Fig. 11.11). The threaded portion of the bolts shall be longer than the fitting portion of the shaft. The rig is to be mounted in position by means of a hole provided in the rotor or flywheel disc.

The rotor is to be heated and the shaft cooled down prior to fitting. Heating can be effected by hot air or with the aid of resistors supplied with voltage from welding transformers. In the former case, the rotor is to be placed in a special wooden case lined inside with sheet steel. The hot air temperature shall not exceed 90° C.

The rotor hub bore is to be measured several times till the desired diameter is obtained. This diameter shall increase as a result of heating by a value equal to three negative allowances but not less than by 0.1 mm per every 100 mm of

the shaft diameter. In the course of rotor heating care shall be taken to prevent heating of windings above 90°C. The hole dimensions can be checked by means of an inside calliper, an inside micrometer, or a special metal gauge made in the form of a disc, 3 to 5 mm thick, with a welded-in grip. The gauge shall have a diameter larger than the cold hub bore by three negative allowances.

Example. According to Table 8.3, with a shaft of 360 mm in diameter, the negative allowance for the hole system, 2nd accuracy grade, at a force fit makes up 0.4 mm maximum and 0.3 mm minimum or 0.35 mm average.

For such a case, the hole diameter will be $360 - 0.35 = 359.65$ mm and the gauge diameter will be, respectively, $359.65 + 0.35 \times 3 = 360.7$ mm.

It will be good practice, before fitting the hub, to cool the shaft in a wooden box packed with dry ice.

The bolts of the rig illustrated in Fig. 11.11 shall be turned in uniformly and uninterruptedly so as to avoid misalignment and seizure and, hence, to prevent excessive force applied at fitting. The rotor shall be shrunk onto the shaft quickly; in the event of a stop, measures shall be taken to complete its fitting or to remove the rotor from the shaft. For the removal, use can be made of a hydraulic jack or puller bolts and a cross-piece assembly. In exceptional cases, the rotor hub may be heated with a circular gas burner.

While fitting the rotor onto the shaft, care shall be taken to provide accurate alignment of the keyways on the shaft and on the rotor hub. To this end, an auxiliary feather key with a fillet shall be fitted into each keyway. Due to the fillet the key can be easily removed after the rotor hub is mounted on the shaft. The key shall be one third as long as the keyway. A threaded hole is provided in the feather fillet. The latter also serves to limit the feather movement through the keyway. The feather can be removed by means of a bolt inserted in the threaded hole of the fillet or by means of a wedge driven into the joint between the fillet and the hub face.

The key is to be selected so as to provide its tight fitting within the shaft and hub keyways. The key has a small

clearance over its height between the top surface and the bottom of the hub keyway. If a tangent or wedge-shaped key is used instead of a prismatic key, it shall be inserted into the keyways after the rotor hub is mounted on the shaft.

Whenever a flywheel is to be mounted on the shaft, the procedure shall be the same as for the rotor hub. The flywheel, however, may be heated to a higher temperature (150-180°C). For heating, use can be made of gas burners. To prevent local overheating, the gas burners must be moved all the time over the flywheel circumference. This method, however, may cause cracks within the hub as a result of local overheating.

The method of heating for the rotor or flywheel is selected to suit environmental conditions and shall be stipulated in the construction work organization plan.

11.6. Installation of Non-Split Stator

After an appropriate inspection the stator shall be mounted on the bed plate with reference to the factory marks or to the holes for bolts and check pins.

Then the wire shall be stretched along the bearing pedestal centre lines (this wire is to be removed before delivering the stator to the bed plate). The first thing to do is to check the position of the main longitudinal centre line, and the stator is to be set in position so that its longitudinal centre line coincides with the shaft line.

The stator position is to be checked by the same method as that described hereabove for checking the bearing pedestals. Four measurements are to be made with an internal micrometer, *viz.* two measurements in the horizontal plane and two ones in the vertical plane. A final installation is to be carried out after the rotor is introduced into the stator and the shafts are aligned.

The stator position on the horizontal plane is to be adjusted by moving it over the bed plate surface in the desired direction. The stator height is to be adjusted by changing the number and thickness of pads and shims under the stator feet.

11.7. Mounting the Rotor in the Stator

This procedure is a very complicated one and requires particular care, as the gap between the stator and the rotor is very small. Therefore, careless handling may cause damage to the stator and rotor stacks and windings.

Prior to starting this operation, remove the front bearing pedestal on the slip-ring or commutator end. Methods to be used for introducing the rotor into the stator depend

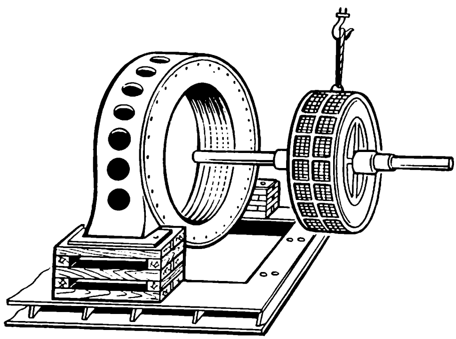


Fig. 11.12. Driving the rotor into the stator mounted on a stack of sleepers

on the construction of the latter. The stator bore may have its lower mark either above or below the bed plate surface.

In the former case, raise the stator on pads over a small height so as to ensure a passage for the shaft extension above the lower shell of the rear bearing. In the latter case, mount the stator on a stack of sleepers and not directly on the bed plate. The sleepers are to be placed under the stator feet so that the rotor can be easily introduced into its bore, as is shown in Fig. 11.12.

Prior to driving the rotor into the stator, cover the bottom of the stator bore with pressboard so as to protect its iron stack against damage. After the stator is mounted on a stack of sleepers, drive the rotor therein as follows: sling

the rotor with a fastening rope and suspend it horizontally whereupon drive it to the stator bore by means of a crane.

Place the rotor in a position in which the air gap between the rotor and stator stacks is approximately uniform throughout the entire circumference (check visually).

In order to prevent damage to the rotor by the fastening rope, cover the rotor barrel with planks before slinging. These planks will take the sling pressure.

In the event of a long shaft, sling the rotor by the two ends of the latter, bring it to the stator and push till the shaft extension comes out on the other end of the stator. In such a position, lower the rotor on wooden beams or a trestle provided with special recesses to hold the rotor in position. After that sling the rotor and carefully drive it into the stator till the shaft journal is mounted in the bearing. In the action take care to keep the stator stack and winding in good condition. It is good practice to illuminate the opposite end of the stator bore with a lamp so as to check the air gap between the stator and rotor stacks while the rotor is driven in. Having introduced the rotor, lift the stator a little and remove temporary pads from under its feet.

If the stator bore is arranged below the bed plate surface, raise the stator and mount its feet on sleepers so that the bore is set slightly above the upper surface of the bed plate. With a sufficient length of the shaft, proceed with the rotor mounting into the stator as described above. Having introduced the rotor, fit in place the second bearing pedestal which has been removed for the time of mounting and lower the rotor onto the stator stack covered with pressboard. Thereupon, sling the stator and lift it together with the rotor so as to remove the sleepers from under its feet. Slowly move down the whole assembly and fit the shaft journals into the bearings. Using puller bolts and threaded holes provided in the stator frame feet, lift the stator, fit the levelling pads and shims under its feet again.

If the crane capacity is insufficient to lift the stator and the rotor simultaneously, first lower one end of the assembly and then the other at the same time replacing the sleepers with pads and shims. When using this technique, sling each side being handled separately.

In the event of a short shaft which is inconvenient for pushing the rotor into the stator bore, an extension shaft shall be used to elongate the rotor shaft.

The extension shaft is usually supplied as standard together with the rotor and the main shaft by the Manufacturer. The extension shaft is to be attached to the main shaft carefully so as not to injure the ground surfaces of the shaft journals.

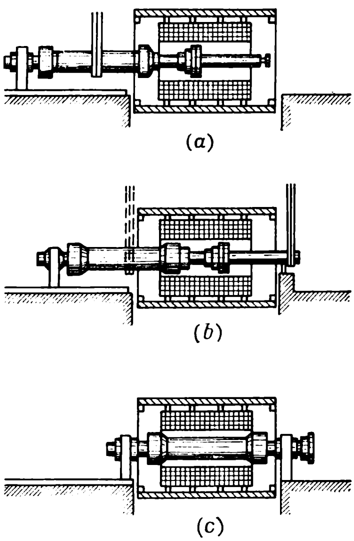


Fig. 11.13. Driving the rotor into the stator with the aid of an extension shaft

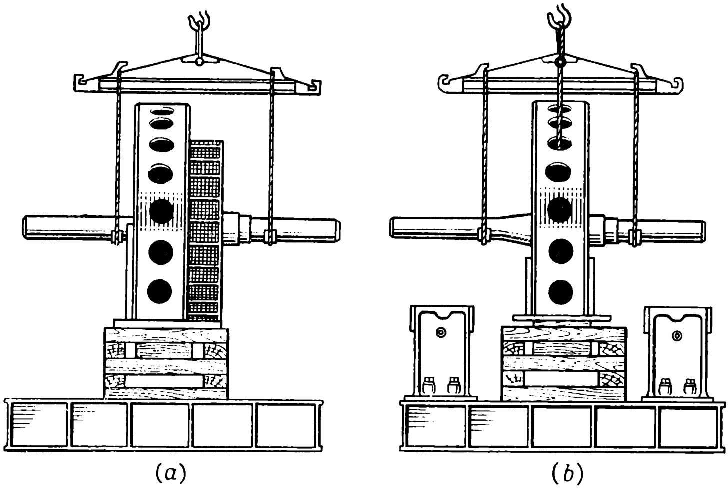
(*a*) starting operation; (*b*) intermediate operation (the extension shaft is slinged); (*c*) final operation (the extension is removed)

Figure 11.13 illustrates the procedure of introducing a short-shaft rotor into a stator with the aid of an extension shaft.

In the absence of an extension shaft the short-shaft rotor can be introduced into the stator by changing the points of attachment of slings in the course of the procedure, as is shown in Fig. 11.14.

After the stator and rotor are mounted in position, check for clearances between the shaft journal necks and the butt ends of the bearing shells.

These clearances are required to afford an axial play while the machines are running. The axial play is adjusted according to the Manufacturer's instructions or, if such are not available, the following requirements shall be taken into account. For the shaft journals having a diameter of up to 200 mm the axial play shall be within 2 to 4 mm and for those whose diameter is larger than 200 mm it shall make up 2 per cent of the shaft journal diameter. The axial play of the shaft is to be set upon the assumption that thermal expansion of the shaft takes place starting from its centre.



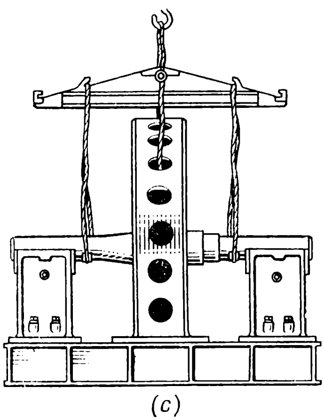


Fig. 11.14. Introducing the rotor into the stator by changing the points of attachment of slings in the course of the procedure

(a) slings are attached to the arrangement; (b) rotor is introduced and the machine is raised; (c) rotor is fully introduced into stator

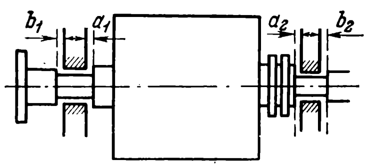


Fig. 11.15. Setting the axial play of the shaft

a_1, a_2, b_1 and b_2 — clearances between the necks of the shaft journals and the butt ends of the bearing shells

For instance, clearance a_1 of a cold shaft must be greater than clearance b_1 (Fig. 11.15).

For multimachine sets having their shafts joined via rigid flanged-face couplings the shaft play is to be set taking into account that at an increase in temperature by 40°C the shaft becomes 0.5 mm longer per every metre of its length.

The axial clearances shall be adjusted by shifting the bearing pedestals.

11.8. Stator and Rotor Mounting in the Case of Split Stator

Large alternating-current machines with a stator diameter exceeding 3 m as well as direct-current machines with such and a still smaller stator diameter are furnished with split stators. Before mounting a split stator, levelling pads and shims are set on the bed plate and then the bottom half of the stator is installed without removing the previously adjusted bearing pedestals. Prior to lifting the bottom half of the stator, wooden distance bars are fixed in the split joint so as to protect the bottom half against bending and breakage by slings. For the same purpose, before lowering the bottom half of the stator onto the bed plate, a supporting jack is to be erected. The jack is usually supplied as standard equipment of the machine.

The bottom half of the stator shall be adjusted by means of the stretched wire which was used for adjusting the bearing pedestals. The wire is to be removed before mounting the stator and after the latter is installed it shall be stretched again. After the stator bottom half is adjusted, the wire shall be removed and the rotor is to be mounted in the bearing pedestals. Its position is to be checked up by using one of the above-described methods. Prior to checking it is necessary to adjust the air gap between the rotor stack and the bottom half of the stator by changing the number and thickness of shims placed under the stator feet. In the action, the stator is to be slightly raised by means of the supporting jack.

After the adjustment of the air gaps between the stator and the rotor, the split joint surfaces of both the stator halves are to be thoroughly cleaned of dirt and the top half

is to be installed. It is recommended to fit perforated steel sheets on the split joint of the bottom half so as to avoid an unnecessary contact between the rotor surface and the top half of the stator while the latter is lowered. Perforations in the steel sheets make the latter easy to remove after the top half of the stator is installed in position.

A particular care is needed when mounting the top stator half of induction motors where the air gap is very small.

In the event of a displacement of fastening holes due to the effect of the mass of the stator top half, these holes can be aligned by adjusting the supporting jack pressure.

The joint between the two halves in dc machines shall be tight, without a clearance. This is to be checked with a feeler gauge after the bolts are tightened up. Sheets jutting more than 0.2 mm beyond the joint are to be carefully filed off and the joint is to be cleaned with a metal brush and blown down with compressed air.

The bottom half shall not be bolted to the bed plate until it is joined and bolted with the top half and the air gap is checked between the stator and the rotor. The air gaps are to be checked twice: (a) after the two halves are joined together and (b) after the bolts securing the stator to the bed plate are fully tightened up.

Installation of multimachine sets shall be started with mounting the stator and rotor of the drive motor and only after that the dc machines shall be erected. In the case of split stator frames, the bottom halves of machine frames shall be first mounted on the respective pads and shims on the bed plates. In handling the armatures slings shall be attached to the shaft extensions and not to the armature barrel and a distance beam shall cover the armature barrel so as to prevent damage to the end windings and commutator by the steel-wire rope. A special-purpose lifting beam may be used as alternative for handling the armatures.

11.9. Check-up and Adjustment of Air Gaps Between the Stator and the Rotor

The air gaps between the stator and the rotor (armature) are to be checked and finally adjusted after the shafts are fully aligned and the halves of the dc machines are set in

their respective positions and bolted to the bottom half-frames.

The air gaps are to be adjusted with the aid of wedge-type gauges (see Fig. 6.3) on both sides of the rotor or armature:

in the case of salient-pole machines, at every pole under the centre of the pole shoe;

in the case of nonsalient-pole machines, at four points for smaller rotors and at eight points for larger rotors.

The best way to check the air gaps in machines with salient-pole rotors is to measure it between one and the same pole and different points of the entire stator circumference (at four or eight points of the stator core).

The air gap between the stator and rotor stacks of a high-frequency generator having a very small gap shall be checked and adjusted before the alignment of its shaft with the drive motor shaft because both the generator and the drive motor are furnished with two bearings.

The permissible difference between the minimum and maximum values of air gaps in per cent of the arithmetic mean shall not exceed 10 per cent for induction machines, 10 per cent for low-speed synchronous machines, 5 per cent for high-speed machines, 10 per cent for dc machines with a lap winding and with an air gap of up to 3 mm under the main poles or 5 per cent for those with an air gap over 3 mm under the main poles; dc machines with a wave winding may have this difference 2 or 2.5 times as high. The air gaps between the armature and the commutating pole shall have a difference not to exceed 5 per cent. The air gap shall be uniform throughout the entire circumference accurate to 10 per cent for all the electrical machines.

The air gaps are adjusted by a suitable selection of shims fitted under the stator frame feet and by turning the stator relative to the longitudinal centre line.

The air gaps of high-frequency generators are adjusted with the aid of shims supplied by the Manufacturer and by turning the stator with the aid of screw clamps. Shims bearing identification numbers shall be fitted in their respective places.

The air gap in the top portion of the generator is recommended to be set 0.05 to 0.1 mm larger than in the bottom portion.

The most popular are two methods of measuring the relative nonuniformity of air gaps for high-frequency generators.

1st method. Measuring coils 1 and 2 are fitted on two opposing pole teeth of the stator and emfs E_1 and E_2 are induced in these coils under specified conditions. Since the emf of every coil is inversely proportional to the air gap length at the given points, this condition can be expressed through the equation

$$\frac{E_1-E_2}{E_1+E_2}=\frac{\delta_2-\delta_1}{\delta_2+\delta_1}$$

where δ_1 and δ_2 stand for the lengths of air gaps between the rotor and the stator pole teeth carrying coils 1 and 2.

Meanwhile

$$\frac{\delta_2-\delta_1}{\delta_2+\delta_1}=\frac{e}{\delta_{av}}=\varepsilon$$

where $e=\frac{\delta_2-\delta_1}{2}$ = displacement of the rotor axis relative to the stator axis (rotor eccentricity)

$\delta_{av}=\frac{\delta_2+\delta_1}{2}$ = average length of the air gap

$\varepsilon=\frac{e}{\delta_{av}}$ = relative eccentricity of the rotor

Since

$$\frac{E_1-E_2}{E_1+E_2}=\frac{\delta_2-\delta_1}{\delta_2+\delta_1}=\frac{e}{\delta_{av}}=\varepsilon$$

the relative eccentricity of the rotor at a plane passing through the centres of the stator teeth carrying coils 1 and 2 is defined as the ratio of the E_1 and E_2 difference to the E_1 and E_2 sum.

Relative eccentricity measuring instruments are not available.

Employed as an eccentricity indicator is a moving-coil ratio-meter used for temperature measurements.

2nd method. Measurements are made by means of a type M119 milliweber meter. The milliweber meter depends for its operation on applying electric current to its moving coil through torqueless coils with the result that when the moving coil does not carry current it can take any position.

Measuring coils 1 and 2 are fitted on two opposing stator pole teeth like in the 1st method. An emf is induced in the measuring coils as the generator field current is cut in and out; this causes the moving coil of the milliweber meter to turn through an angle proportional to the magnetic flux cutting the turns of the measuring coils.

The milliweber meter readings are taken at the maximum angle of turn of its moving coil. The relative eccentricity will be found from the equation:

$$\varepsilon = \frac{C_1 - C_2}{C_1 + C_2}$$

where C_1 = meter scale reading in measuring the emf of coil 1

C_2 = same in measuring the emf of coil 2

Measurements are to be taken while the machine is not running.

The procedure is as follows:

short out the field winding by means of a dropping resistor;

set a current through the field winding equal to 50 per cent of the rated value;

turn the rotor so as to set its teeth against the stator teeth carrying coils 1 and 2;

set the milliweber meter pointer at the centre of its scale;

connect the meter to the leads of coil 1;

cut out the field current and put down the meter readings;

cut in the field current and make sure that its magnitude is the same;

set the meter pointer at the centre of the scale;

connect the meter to the leads of coil 2;

cut out the field current and put down the meter readings;

cut in the field current and make sure that its magnitude is the same;

find the relative eccentricity from the equation

$$\varepsilon = \frac{C_1 - C_2}{C_1 + C_2}$$

If the rotor relative eccentricity ε, as measured in the horizontal plane, is positive, the stator shall be displaced to the left and if it is negative, the stator shall be shifted to the right through distance $e = \varepsilon\delta_{av}$ (mm).

In the event measurements were made in the vertical plane, the stator shall be raised at a positive value of ε and lowered at a negative value of ε over a distance $e = \varepsilon\delta_{av}$ (mm).

The stator is moved horizontally by means of a puller screw arrangement welded to the bed frame and its vertical position is adjusted by means of shims placed under its feet or by turning the stator about its longitudinal axis.

In assembling the machine care shall be taken to arrange symmetrically the rotor and stator fields. To this end, the iron stacks of these parts shall be arranged symmetrically. It shall be borne in mind that an asymmetry causes an interaction between the stator and rotor fields which brings in stray axial forces tending to set the rotor in the centre of the stator field. In the course of a final adjustment of the gap the rotor stack shall be checked and set in the correct position relative to the stator stack. In the case of dc machines it will be necessary, in addition, to set the armature stack symmetrically relative to the main poles.

In order to check the stator and rotor fields for symmetrical arrangement measure the clearance between the butt end of the pole shoe and the extreme iron stack of the stator at both ends of every pole, i.e. on each side of the machine. The difference in the arithmetic means determining the asymmetry of these fields shall not exceed 1 mm.

The results of these measurements after the final adjustment of air gaps shall be entered in the installation and wiring log of the machine.

11.10. Installation of Bed Plates for Drive Motors

Drive motors shall be installed only after the driven mechanisms are mounted and their shafts are fixed in a not-to-be-changed position. That is why, the installation procedure for drive motors will be different as compared to that for motor-generator sets.

Prior to mounting the bed plates, determine the motor shaft elevation for the given height of the foundation, taking into account the thickness of standard pads and shims pla-

ced under the bed plate. The distance between the bed plate mounting surface and the motor shaft centre line shall comply with the Manufacturer's installation drawings. If the shaft centre line is higher than that of the driven mechanism, it will be necessary to make recesses on the foundation at the places of installation of shims. Bear in mind that the distance between the foundation surface and the lower edge of the bed plate shall be at least 50 mm. If this condition cannot be met, undercut the foundation over the entire surface to obtain the desired distance.

After having cleaned off the foundation, fit the pads and shims at places specified by the factory drawings, mount the bed plate on them and drive in the anchor bolts. Erect the bearing pedestals on the bed plate (place them on shims), install the lower half of the dc motor field frame and mount the armature in the bearings. A dc motor having a nonsplit field frame or an ac motor having no outboard bearings shall be erected on the bed plate in an assembled condition.

In mounting ac motors with outboard bearings, first mount the stator on the bed plate, then drive the rotor into the stator following the procedure laid down in Section 11.7.

In order to set the motor shaft in a correct position relative to the driven mechanism shaft, move the bed plate horizontally and vertically (with the bolts fastening the bearings on the bed plate turned in).

Check the shafts for correct mutual positioning by means of a straightedge placed on the rims of the half-couplings.

Having aligned the shafts in the horizontal and vertical planes, turn in the anchor bolts. In the action, use shims to retain the aligned position of the shafts. For the final alignment and measurements thereof proceed as described in Chapter Sixteen.

A new installation technique for the bed plates of drive motors has been used since 1971. The installation height for the given height of foundation is determined by calculations.

Prior to making calculations, it will be necessary to obtain from the Designer the bench mark of the driven mechanism shaft. Calculations are to be made according to the bench marks specified in the reference survey drawing of the foundation, overall dimensions of the drive motor, and

the shaft centre line height above the datum level of the building (Fig. 11.16):

(a) thickness x of stacks of shims and wedges placed under the bed plates is to be found, depending on the height of

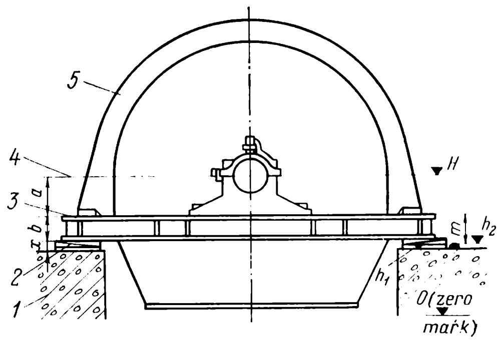


Fig. 11.16. Sketch showing the drive motor and foundation with basic fixing dimensions

1 — foundation; *2* — stack of wedges and shims; *3* — bed plate; *4* — shaft centre line; *5* — drive motor

the upper surface of the foundation, from the equation:

$$x = (H - h_1) - (a + b) \tag{11.1}$$

where H = bench mark of the shaft centre line specified by the Designer

h_1 = bench mark of the foundation surface which may be different at different points (to be determined by surveying the foundation)

a = distance from the upper surface of the bed plate to the centre line of the drive motor shaft (to be found from the dimensional drawing of the drive motor)

b = bed plate height (to be found from the dimensional drawing of the drive motor)

(b) distance m between the upper mounting surface of the bed plate and the bench mark is to be determined from the equation:

$$m = H - (h_2 + a) \tag{11.2}$$

where h_2 is the bench mark (to be found by surveying the foundation).

Since the h_1 value may be different for different points of the foundation surface, thickness x is to be calculated for every stack of shims.

Example. Thickness x for two bed-plate mounting points *I* and *II* and distance m between the upper mounting surface of the bed plate and the bench mark (Figs. 11.17 and 11.18) are to be found.

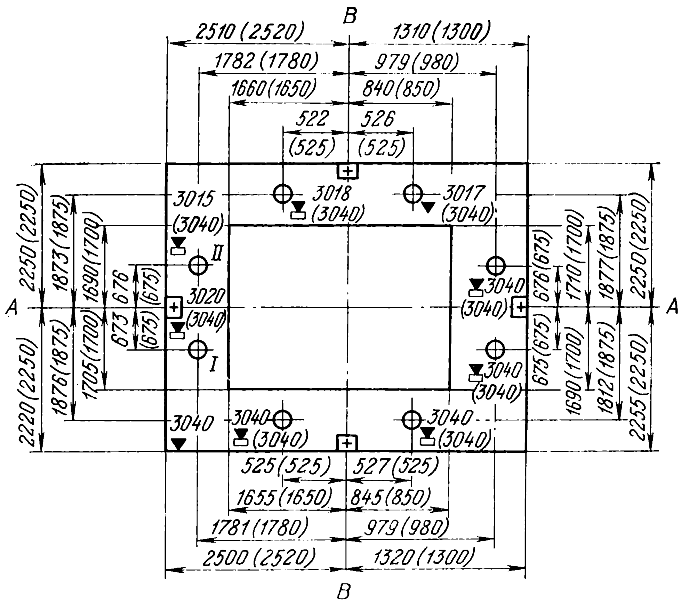


Fig. 11.17. Drive motor foundation survey plan

AA and *BB* — main centre lines of the motor; design dimensions and bench marks are given in brackets and actual ones are without brackets

From the foundation survey data (Fig. 11.18) we know that the actual height of the foundation near the left-hand anchor-bolt holes marked on the drawing with numerals *I* and *II* is

$$h_{\mathrm{I}}^{\mathrm{I}} = 3020 \text{ mm} \quad \text{and} \quad h_{\mathrm{I}}^{\mathrm{II}} = 3015 \text{ mm}$$

Height H (bench mark of the driven mechanism shaft line), according to the design data, equals 3780 mm (Fig. 11.18). Distance a

from the upper surface of the bed plate to the centre line of the drive motor shaft, according to the design drawing of the motor, is 510 mm (Fig. 11.18) and the bed plate height b = 210 mm. The bench mark h_2,

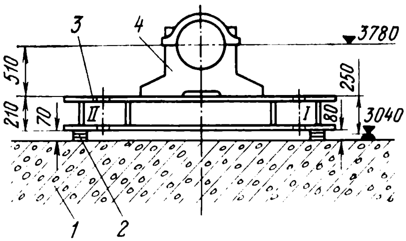


Fig. 11.18. Installation of bed plate with reference to the foundation survey data and the installation drawing

1 — foundation; *2* — stack of shims; *3* — bed plate; *4* — bearing pedestal

according to the foundation survey data, is 3030 mm (Figs. 11.17 and 11.18). With these data in view we find:

(a) the thickness of stacks of shims for different points on the foundation:

$$x_1 = (H - h_{\mathrm{I}}^{\mathrm{I}}) - (a+b) = (3780 - 3020) - (510 + 210) = 40 \text{ mm}$$

$$x_2 = (H - h_{\mathrm{I}}^{\mathrm{II}}) - (a+b) = (3780 - 3015) - (510 + 210) = 45 \text{ mm}$$

(b) the height from the upper mounting surface of the bed plate to the bench mark:

$$m = H - (h_2 + a) = 3780 - (3030 + 510) = 240 \text{ mm}$$

Prior to mounting the bed plates, draw out the longitudinal and transverse centre lines of the drive motor on their surfaces. To this end, use a straightedge placed on the outside of the fastening bolts of the stator and bearing pedestals, as is shown in Fig. 11.19.

Draw out the centre lines between the points of intersection shown by the straightedge. Use a stretched wire for laying out the lines.

The thickness of stacks of metal shims to be placed under the bed plates depends on the height of the foundation and on data obtained from the above calculations. The bed plates mounted on shims are to be set down by turning in the anchor bolts. Then the bed plate is to be checked for correct positioning on the foundation by aligning the longitu-

dinal and transverse centre lines of the drive motor marked on the foundation with those drawn out on the bed plates.

The bed plate is to be levelled off by means of wedges and checked for correct levelling by a straightedge placed on the upper mounting surface of the bed plate and a meter rule placed on the bench mark. Before the anchor bolts are fully tightened, the bed plate shall be positioned so that the height from its upper mounting surface and the bench

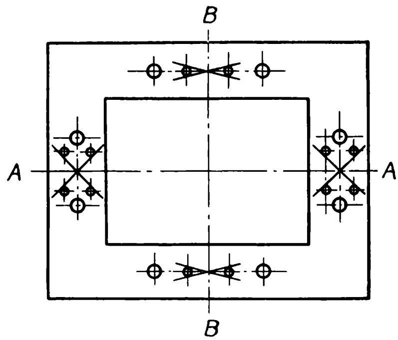


Fig. 11.19. Marking-out of longitudinal and transverse centre lines of the motor on the bed plate

AA — motor longitudinal centre line; *BB* — motor transverse centre line

mark be 1 mm below the calculated value. This tolerance is recommended to allow for errors brought in during surveying and measurements.

In tightening up the anchor bolts keep the bed plate mounting surface in the levelled-off position. To this end, make use of a shaft level and a hydrostatic level.

Before mounting the drive motor make sure that the driven mechanism shaft is properly levelled off. If this is not the case, apply to those who installed the driven mechanism. In further installation of the drive motors proceed as is described for motor-generator sets.

In some instances dc motors of the main drives of rolling mills may have separate bed plates for bearing pedestals and frames. Such bed plates, as well as bearing pedestals and frames, are fastened to the foundation with common bolts (Fig. 11.20), and the mounting plates are fitted with

adjusting screws which function as jacks. Supporting plates are placed on the foundation under these screws. The bearing pedestals and the stator frame can be accurately levelled off by means of these screws, dispensing with thin adjusting shims. The adjustment over, permanent pads are

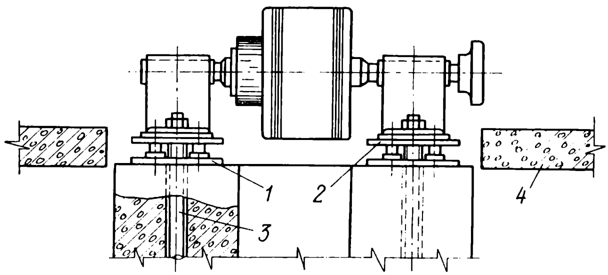


Fig. 11.20. Fastening the bearing pedestal and the bed plate with a common anchor bolt

1 — supporting plate; 2 — mounting plate with adjusting bolts; 3 — anchor bolt; 4 — hung floor

inserted under the plates in the form of, say, opposing wedges welded to one another and to the plates.

For mounting the drive motor components on separate bed plates proceed as follows:

flatten the foundation surfaces to receive supporting plates and mount the bed plates on the latter;

set the bearing pedestals in position and drive the anchor bolts into the holes in the foundation through the holes in the plates;

while the anchor bolts are slightly turned in, level off the bearing pedestals with the aid of the adjusting screws at the same time setting them accurately against the stretched wires indicating the main centre lines;

mount the armature in the bearings and align it with the driven mechanism shaft.

For further alignment of the shafts and installation of the motor proceed in the same way as with motor-generator sets.

The main bearing pedestals of the drive motor on the side of the rolling mill stand reduction unit are furnished

with babbit-lined rings. These rings serve to take axial thrusts from the reduction unit arising at the moment a billet is caught by the driving rollers of the stand (especially during the first pass). That is why the drive motor shaft shall be positioned so that in its extreme position (on the reduction unit side) a clearance of 1 or 2 mm be provided on the butt end of the half-coupling hub.

The lateral motion of the shaft can be afforded by standard jacks or wedges. The supporting side jacks or wedges shall not be released till the anchor bolts are fully tightened so as not to disturb the aligned position of the shafts.

After the drive motor shaft is aligned with the mill stand reduction unit shaft and the bearing pedestals are fixed in position, remove the armature from the bearings for mounting the motor frame. The latter is to be installed in the same way as the bearings. This done, fully assemble the motor following the appropriate instructions.

CHAPTER TWELVE

Installation of Electrical Machines Dispatched in an Assembled Condition

Electrical machines dispatched by the Manufacturer in an assembled condition are commonly not disassembled on the site of installation. The scope and kind of inspection depend on the condition of their shipment and storage. A detailed description of inspection procedure for machines coming in an assembled condition is given in Chapter Ten.

Prior to installing the machines shall be blown down with clean compressed air to remove dust from their surfaces, whereupon the insulation of the stator and rotor windings shall be checked for condition with the aid of a megger.

Motor-generator sets are usually dispatched assembled on a common bed plate and adjusted for normal running. The only thing to do is to install and level off the bed plate carrying the assembled machines and to bolt it to the foundation. The bed plate is to be levelled off and adjusted in position against bench marks and centre lines in compliance with installation drawings. A hydrostatic level makes it possible to rather accurately check the bed plate for a correct levelling.

For the remaining steps refer to directions laid down in Chapter Eleven.

The drive motors dispatched in an assembled condition shall be mounted only after the driven mechanisms are installed and their shafts are fixed in position. Therefore, every drive motor coming in an assembled condition shall be installed individually with due account for the elevation and location of the driven mechanism shaft and the actual height of the motor foundation. In the action, reference shall be made to instructions set forth in Chapter Eleven.

CHAPTER THIRTEEN

Installation of Electrical Machines with Segmental Bearings

High-frequency generators are furnished with bearings of a unique design. They consist of a segmental shell into which a special babbit bearing lining (pad) is cast.

Figure 13.1 illustrates the general arrangement of the segmental bearing. Each segment is free to move within its seat and can set itself in a number of centred positions relative to the shaft journal. The split joints of the segmental bearing shells are slightly inclined horizontally and do not coincide with the split joint of the bearing pedestal cap.

In order to remove the bearing shells from the seat in the bearing pedestal turn them till their split joint is aligned with that of the bearing pedestal cap. Then extract the guide pins and bolts bracing the upper and lower shells together, remove the upper shell and after that roll out the lower shell.

Such steps are indispensible in the assembly and disassembly of segmental bearings as any excessive force applied to the upper shell may cause its damage.

As the high-frequency generators have a very small air gap between the stator and rotor stacks (0.9 to 1.7 mm) the shaft shall be lifted only with the aid of hydraulic or wedge jacks when it is necessary to drive out the bearing shells. The segmental bearings shall be fitted and adjusted following a definite procedure before assembling the generators. The procedure is started with fitting the segmental shells.

Before mounting the generators, a metal mandrel (Fig. 13.2) shall be constructed. The mandrel diameter shall be 0.2 mm larger than the actual diameter of the shaft journal and its length shall be 50-60 mm greater than the width

of the bearing shell. The working surface of the mandrel shall be polished.

The effective area of the segments bearing on the shaft journal is to be checked by paint. To this end, smear the

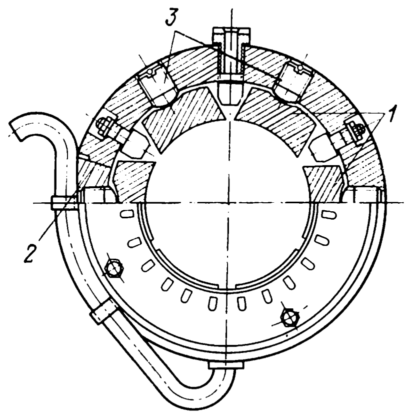


Fig. 13.1. Segmental bearing. General arrangement
1 — segments; 2 — split joint of bearing shells; 3 — adjustment screw

thoroughly polished surface of the mandrel with a thin film of paint whereupon mount first the lower shell and then the upper shell onto the latter setting them in the working posi-

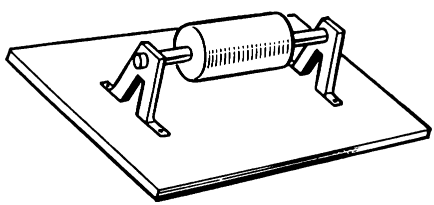


Fig. 13.2. Mandrel

tion. Then repeatedly turn each bearing shell through an angle of 45° at the same time pressing the shell with hand to the mandrel.

In the action spots of paint will appear on the surfaces coming in contact with the mandrel. Not more than five or six spots of paint per every 25 × 25 mm area shall be admitted on the segments. If the number of paint spots exceeds the specified value, the bearing surface of the segment shall be scraped whereupon the above-described check shall be repeated. After that the segments shall be set in a correct position relative to the shaft journal.

The desired clearance between the generator rotor shaft journals and the segmental bearing shells is to be adjusted against a mandrel having a diameter 0.2 mm larger than that of the shaft journal so as to ensure the desired clearance after the bearings are assembled. For setting the segments to fit the mandrel diameter, mount the segmental shells on the mandrel, the segments being joined together with studs so as to eliminate clearances at the split joints of the shells.

Turn the interlinked shells about the mandrel and, using a dial gauge, check the segments for the degree of fitting to the mandrel surface. In the event of insufficient fitting, adjust the segments by means of their screws till a tight fitting is obtained. The clearance between the bearing shells and housing shall be within the range of 0.018 to 0.07 mm as determined by the lead impression method.

CHAPTER FOURTEEN

Installation of Shaft Couplings

14.1. Rigid, Semi-Rigid, and Flexible Connection of Shafts

The shafts of different electrical machines are interconnected or connected to those of the driven machines and mechanisms by means of various couplings which can provide for a rigid, flexible, or semi-flexible connection.

Rigid connection of shafts is used where no relative movement between mating joints is allowed, i.e. where the shafts are to form a solid line.

Rigid connection is afforded by means of flanges forged integral with the shaft (solid forged coupling) or by rigid couplings fitted on the shaft extensions.

Figure 14.1*a* illustrates a solid forged coupling. This type of coupling is used for connecting shafts supported on one end only, in which case the coupling proper serves as the other support.

With such a connection there is usually a projecting spigot, 8 or 10 mm long (or 16 mm long for shafts having a diameter of up to 600 mm), on one flange which fits into a recess on the other flange (or half-coupling). The two flanges mated with a sliding fit are bolted to one another, the bolts being driven into the holes by tapping with a lead hammer. The bolts must be tight within the holes. In some cases the bolts may be tight in the holes of one flange while in those of the other flange there may be a clearance of 0.1 to 0.25 mm (depending on the diameter of the bolt).

As has been mentioned above, a rigid connection can be effected by means of rigid couplings. These are the flanged-face and geared couplings of the M3H and M3У types.

The flanged-face couplings are primarily used for jointing the shafts of electrical machines in motor-generator sets.

The flanged-face coupling illustrated in Fig. 14.1*b* consists of two half-couplings *1* and *2* mounted on the exten-

sions of the shafts being coupled. The half-couplings are provided with projecting spigots which fit into the recesses on the mating counterparts. The half-couplings are fastened by means of specially machined bolts *3* push-fitted into the reamed holes of the half-couplings. Provision is made for

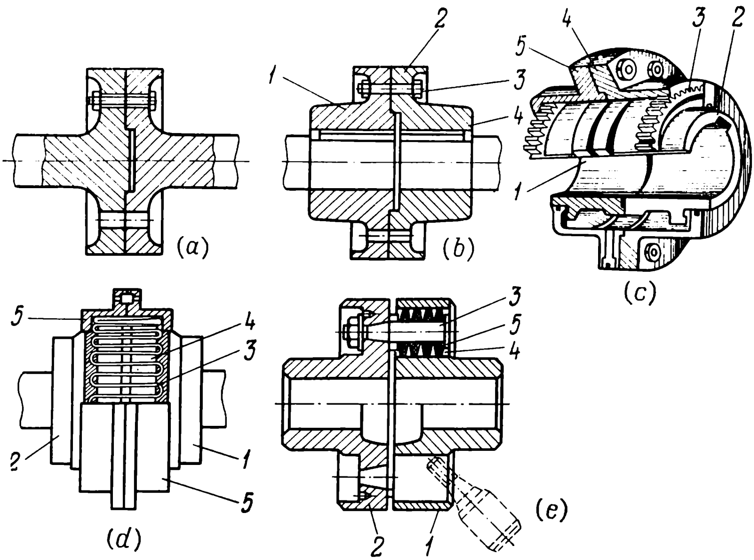


Fig. 14.1. Solid-forged connection of shafts and shaft couplings

a key *4* which prevents turning of the half-couplings on the shafts. Lock screws turned in at the ends where the half-couplings are mated with the shafts prevent the axial movement of the half-couplings. These screws are not shown on Fig. 14.1*b*.

In the event some of the holes of the half-couplings in the flanged-face couplings fail to be aligned, they can be reamed with the aid of a conical or universal reamer. To this end both the half-couplings are bolted together with bolts inserted into aligned holes. One of the reamer ends shall be supported by a stop fixed to the bearing pedestal so as to prevent a departure from roundness of holes being reamed out due to a rocking motion of the reamer. The same

stop is to be used to push the reamer forward through the holes of both the half-couplings.

The geared coupling illustrated in Fig. 14.1*c* consists of two sleeves *1* and *2* keyed to the shaft extensions of the machines being coupled. Each sleeve has gear teeth cut on its outer rim. The two sleeves are coupled together by two half-couplings *4* and *5*, each having internal gear teeth which mesh with the teeth on the sleeves *3*. The half-couplings are bolted together.

Semi-rigid connection is used for coupling the shafts of turboalternators with those of steam turbines, and the like. Such a connection can be effected by the use of a variable flexibility coupling of the "Bibby" type which consists of two half-couplings *1* and *2* (see Fig. 14.1*d*), each having flared teeth *4* round the circumference and coupled together by means of a continuous spring *3* threaded between the teeth in a serpentine manner. The spring is the driving member of the "Bibby" coupling. The coupling is covered with a housing *5*.

Flexible connection is employed when it is necessary to allow for a certain amount of shafts misalignment, angular or axial. The type МУВП sleeve-and-peg couplings are most widely used to afford this type of connection of shafts. Such couplings are used, for instance, to couple the shafts of exciting sets of large electrical machines.

The type МУВП sleeve-and-peg coupling is illustrated in Fig. 14.1*e*. It consists of two half-couplings *1* and *2* mounted on the shafts of the machines being coupled. The desired amount of flexibility is provided by pegs or bolts *3* bushed with leather washers *4* or rubber cups clamped with a snap ring *5*. The pegs are fitted with their metal portion into the driving half-coupling with a certain amount of interference, while in the driven half-coupling they enter with their flexible portion with a small clearance.

14.2. Checking the Couplings and Making Them Ready for Mounting

Before mounting a half-coupling on the shaft, irrespective of the methods being used, check the fitting dimensions of the half-coupling hub for compliance with those of the shaft portion to receive the half-coupling.

In addition to this check, make sure that the hub bore and the fitting portion of the shaft are strictly cylindrical (flaring and ovality check). Make use of an internal micrometer and a dial-and-indicator snap gauge to measure the diameters of the hub bore and the fitting end of the shaft, respectively.

In measuring the bore diameter D_{hub} in a hub set the internal micrometer strictly perpendicular to the longitudinal centre line of the bore; bear in mind that even a slight

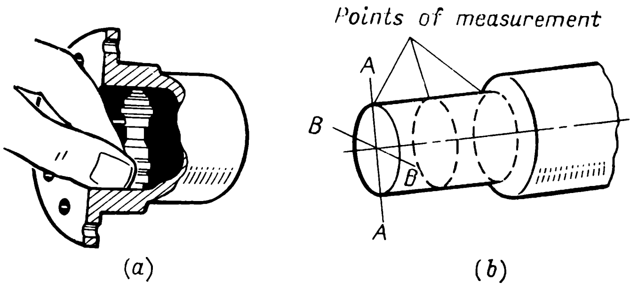


Fig. 14.2. Measurement of fitting dimensions on half-coupling bore (*a*) and on shaft extension (*b*)

inclination of the instrument will yield inaccurate readings (see Fig. 14.2*a*). For checking the micrometer readings, make an additional measurement of the internal diameter at the end of the bore by means of a precision slide gauge.

Take measurements at least at three points over the length of the hub and shaft, at least two measurements being made in two mutually normal surfaces along axes *AA* and *BB*, as is illustrated in Fig. 14.2*b*.

In the event of inadequate fitting dimensions inform the User on the fact so as to take necessary measures. If the fitting dimensions are adequate, take steps to prepare the half-coupling for mounting on the shaft.

First determine the amount of interference (negative allowance) for the half-coupling to suit the operating conditions expected for the machine. To this end, refer to Table 8.3 and the illustrating example to the table. Having determined the amount of interference, make a template for chec-

king the bore of the hot hub. The template is to be in the form of a sheet steel disc, 3 to 5 mm thick, with a grip welded to it, the thicker discs being used for larger diameters and the thinner ones, for smaller diameters. The template diameter shall be larger than the cold hub bore by three negative allowances determined according to Table 8.3.

Prior to heating the half-coupling, make handy the mechanisms and accessories for carrying a hot coupling to the mounting site. The best way for handling a hot half-coupling is to carry it with a travelling crane, a jib crane, or a trolley hoist, its hub being slung by a steel-wire rope loop. Also prepare the half-coupling mounting and pulling arrangements which may be required in the course of their fitting on the shaft. For the construction of these arrangements refer to Section 14.3.

14.3. Heating the Half-Couplings and Mounting Them on the Shafts

Heating. The half-couplings can be heated (a) in an oil bath with oil heated to 130-150°C; (b) by a 1.5 or 2 kW electric heater; (c) by an induction method with commercial-frequency (50-Hz) currents; (d) by gas burners using propane-butane as a burning gas; (e) in a furnace using charcoal or coke, this method being used in exceptional cases only.

Methods (b) and (c) are most suitable for the purpose. The electric heater is to be made of nichrome wire rated at a temperature of 800-900°C, which is wound on an asbocement tube, the length of the tube being equal to that of the half-coupling hub. To speed up the heating process, the half-coupling can be covered on all sides with asbestos pressboard. Place the electric heater *2* in the hub bore of the half-coupling *1* keeping a definite and uniform clearance between the hub and the heater so as to prevent the nichrome wire shorting out through the half-coupling body (Fig. 14.3).

When heating by the induction method, use the half-coupling *1* as a toroidal core, cover it with asbestos cardboard and wind with insulated wire *2* having a cross-sectional area of 50 mm^2. In winding make a few coils each rated at 250 A (Fig. 14.4). Apply voltage to every coil from a wel-

ding transformer. In selecting the sectional area of wire and the number of welding transformers refer to Table 14.1 which specifies the heating temperature of 200-250°C as a rated one. If the regulator fails to set a current of 250 A through a coil, change the number of turns in this coil.

The temperature of the half-coupling is to be checked by means of a thermocouple or, as an alternative, with the aid

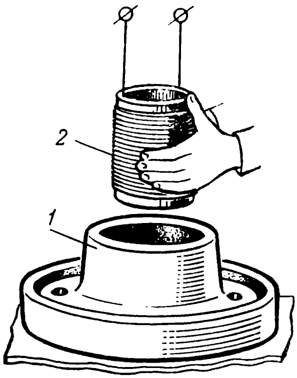


Fig. 14.3. Electric heating of half-coupling

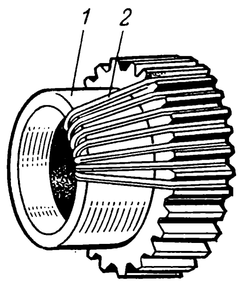


Fig. 14.4. Induction heating of half-coupling

of ПОС-40 tin-lead solder having a melting point of 230-245°C. Pieces of this solder are to be placed on the heated surfaces of the half-coupling.

Mounting the half-couplings. Clean the fitting portion of the shaft and the hub bore of dust, burrs, scores, and nicks. It is good practice to apply a thin coat of oil to the fitting surface of the shaft so as to reduce friction forces in mounting.

Prior to mounting the half-coupling fit a key *1* (Fig. 14.5) to a keyway *4* in shaft *3* and in hub *2* so as to provide a certain amount of interference. The key height shall ensure a clearance *5* between its upper surface and the keyway in the hub.

Small half-couplings using a feather key are to be fitted on the shaft manually in a cold state by uniformly tapping on the butt surface of the hub over the entire circumference with a hammer through a copper or aluminium spacer.

Table 14.1

Cross-Sectional Area of Winding Wire for Induction Heating of Half-Couplings

Half-coupling outer diameter, mm	Number of turns per coil	Number of coils	Number of welding transformers	Approximate time of heating, h
300-500	25	1	1	0.5-1.5
500-800	40	1	1	1-3
800-1200	40	2	2	3-7

Prior to mounting the half-coupling fit the key to the keyway so as to ensure its tight location therein and to provide a small clearance between its top surface and the bottom of the keyway in the hub.

When using this method do not fail to support the opposite end of the shaft with a special rest to absorb the blows

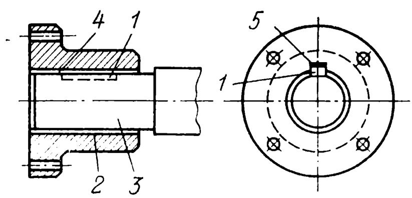


Fig. 14.5. Position of key in the shaft and half-coupling keyway

on the hub so as to prevent the displacement of the bearing bush or damage to the ball or roller bearing.

Tapered shafts are threaded at the portion receiving the conical half-couplings and the latter are mounted by turning in the nut.

The extensions of shafts having a large diameter are provided with threaded holes used to secure a special arrangement for mounting heavy half-couplings *3* (Fig. 14.6). The

arrangement consists of two bolts *1* and a tightening plate *2*. This is the most convenient method.

In mounting the half-coupling onto the shaft make sure that their keyways are accurately aligned. An auxiliary feather key *2* with a fillet (Fig. 14.7) shall be inserted in the keyway on the shaft so as to ensure a correct alignment of the key slots in the course of mounting. The length of the auxiliary key shall be one third that of the key slot.

The fillet on the auxiliary key prevents the latter from being pushed deep into the slot when the half-coupling *3*

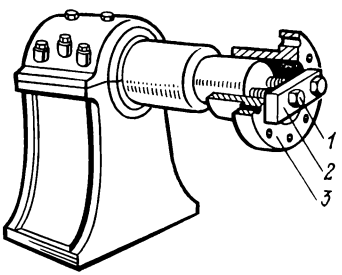


Fig. 14.6. Tool for mounting the half-couplings on large-diameter shafts

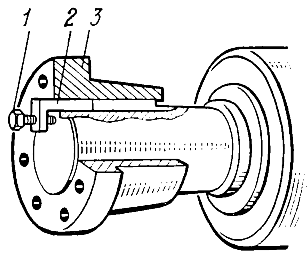


Fig. 14.7. Auxiliary feather key with fillet for mounting the half-coupling

is being mounted. The bolt *1* provided on the fillet is used to remove the auxiliary key. The latter can be also removed by means of a wedge driven in between its fillet and the butt end of the shaft. The auxiliary key shall be fitted tightly in the shaft keyway without misalignment and with a small clearance on its top.

In the course of mounting it may be required to remove the half-coupling which has been already fitted on the shaft. For half-couplings having a diameter of up to 340 mm use can be made of a multipurpose three-arm puller illustrated in Fig. 14.8.

The puller is furnished complete with a hydraulic jack (shown in broken line on Fig. 14.8) joined with a hand-operated plunger pump through a high-pressure hose, type

РВД-10. The puller consists of a steel case *2* and three hinged hooking arms *1*.

The hooking arms are controlled by turning a quadrant *3* having a three-helix profile. The puller shall never be used without the quadrant so as to prevent the hooking arms from spontaneously setting apart. The quadrant is secured to the puller case by means of a snap ring *4*.

Every hooking arm has three holes to control its position in height (see Fig. 14.8).

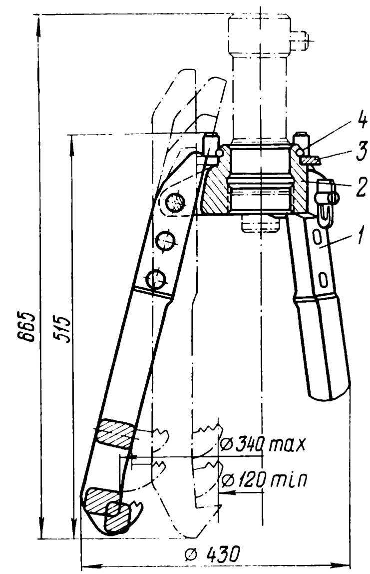


Fig. 14.8. Multipurpose three-arm puller

To remove a half-coupling, turn the hydraulic jack into the puller case as far as it will go. If you fail to take off the half-coupling with the aid of this puller or the half-coupling diameter is larger than 340 mm, use shall be made of a hydraulic puller.

The hydraulic puller illustrated in Fig. 14.9 consists of a ram *10*, an oil tank *9*, a motor *4*, a hydraulic pump *6*, and starting-and-control gear, all housed in a common case. Two hooking grips *1* are accommodated in the press chuck. The distance between the hooking grips can be varied by turning the screw. This puller is suitable to handle items having a diameter as small as 180 mm and as large as 550 mm. For pulling the half-coupling off the shaft, connect the press to supply mains via the flexible cable, slip its eyelets on the crane hook and drive it to the half-coupling which is to be removed. As the motor starts running, the oil contained in the tank is pumped out through a hose *7* into the right-hand portion of the ram which imparts a progressive motion to piston *5* mounted on shaft *3*. In the process the piston rod

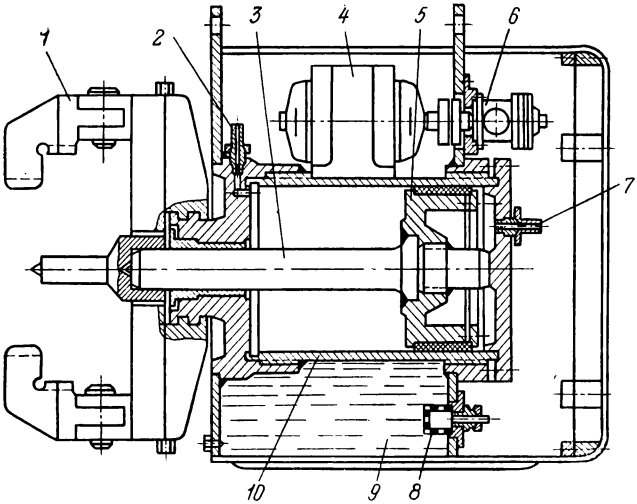


Fig. 14.9. Hydraulic puller

thrusts against the butt end of the machine shaft and pulls off the half-coupling. When oil is delivered to the ram through a hose *2* the piston returns to its original position. The oil is cleaned by means of a strainer *8*. The maximum force of the press is 70 t, the piston stroke is 250 mm.

CHAPTER FIFTEEN

Preparing the Shafts for Alignment

15.1. General Information on the Subject

A proper alignment of shafts of machines and mechanisms being coupled, such as motors and generators or motors and driven mechanisms (pumps, fans, etc.), is one of the basic factors ensuring a trouble-free operation and long service life of electrical machines. The alignment procedure includes two main operations, *viz.* (a) levelling off the centre lines of the shafts (the shaft line) and (b) aligning the shafts, which consists in the elimination of radial and axial displacement of shafts involved.

A correct division of loads between the bearings is ensured by positioning the shafts being coupled so that the butt ends of the half-couplings are parallel in the horizontal and vertical planes and the centre lines of the shafts make up a common line.

The centre line of the shaft of every machine has a slight sag under the effect of the rotor inertia. Therefore, if the shafts of the machines being coupled are strictly horizontal, the half-couplings will set apart at the top due to these sags so that their butt ends are not parallel. In such an event the centre lines of the shafts will not form a continuous line (Fig. 15.1*a*) with the result that in a running motor-generator set the shafts will vibrate producing a detrimental effect on the bearings and other parts of the machines. Moreover, heavy stresses appearing at points *2* and *3* (Fig. 15.1*a*) due to bending moments may cause damage to the shaft journals.

In order to meet the above-specified requirement for the parallelism of the butt ends of the half-couplings, the extreme bearings *1* and *4* shall be slightly raised relative to the bearings *2* and *3* as is illustrated in Fig. 15.1*b*. Under these conditions the common centre line of the two shafts will be

a continuous curvilinear line, as is shown in Fig. 15.1*b* (elastic shaft line), and, when projected on a horizontal surface, it will take the form of a straight line. With this, the butt surfaces of the half-couplings will be parallel.

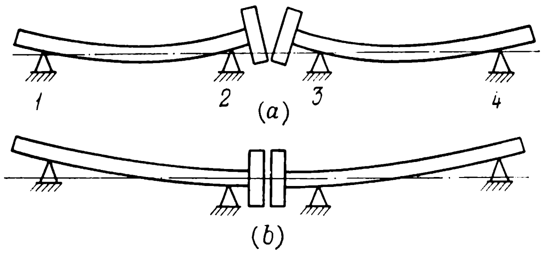


Fig. 15.1. Position of shafts connected via a coupling

For the first step, before starting the alignment, it will be necessary to level off the shaft line so as to position the rotors accurately in strict compliance with the specified requirements.

15.2. Levelling-off the Shaft Line

When two machines (such as a motor and a generator) are installed simultaneously, the shaft line is to be levelled using one of the three below-described methods.

1st method (Fig. 15.2*a*). Set the shaft of machine *I* in a strictly horizontal position. Level *5* placed on every journal of the shaft near bearings *1* and *2* must give readings equal in magnitude and opposite in sign. When this is the case, the straight line passing through the centres of the shaft ends must lie in the horizontal plane.

Align the shaft of machine *II* with that of machine *I*. The level set on the shaft journal at bearing *3* must give the same readings in magnitude and in sign as at the bearing *2*.

2nd method (Fig. 15.2*b*). Set the shaft of machine *I* with one end (at the half-coupling) in a strictly horizontal position so that the level placed on the shaft journal at the bearing *2* reads zero and with the other end slightly raised in the direction shown by an arrow. Align the shaft of machine

II with that of machine *I*. The level set on the shaft journal at the bearing *3* must read zero.

3rd method (Fig. 15.2*c*). Set the shaft of machine *I* in an inclined position so that the level placed on the shaft journals at the bearings *1* and *2* gives readings equal in sign. When placed on the shaft journal at the bearing *3* (machine

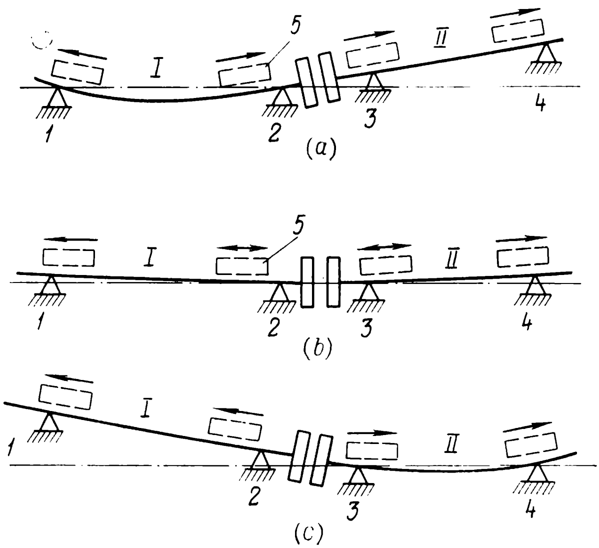


Fig. 15.2. Levelling-off the shaft lines for two-machine set
1-4 – bearings

II), the level must give the same readings in magnitude and sign as at the bearing *2*.

In all these cases the correct setting of the shaft line is recognized by parallel butt surfaces of the half-couplings.

It shall be borne in mind that the slope of the shaft journal shall be measured by the level at four positions of the shaft spaced 90° apart, two measurements being made for every position. For the second measurement the level shall be turned through 180°. The actual slope is to be determined as an arithmetic mean of eight readings.

In the case of tapered shaft journals a correction a_e shall be introduced in the readings. This correction is to be found from the equation

$$a_e = \pm \frac{e}{2kl} \tag{15.1}$$

where e = shaft taper (difference between the diameters over the length of the shaft journal), mm
k = level scale division value, mm/m
l = shaft journal length, m

The sign of the correction depends on the direction of taper. The shaft journal slope, taking into account the taper, can be calculated by adding the correction a_e if the taper and slope of the shaft are unidirectional, or by subtracting this correction if the slope and taper are in different directions.

Determination of the actual slope of the shaft journals by this method makes it possible to avoid errors which might take place due to a distortion of the rotor shaft or eccentricity of the shaft journal. Such defects can be recognized by considerable differences in the readings of a level placed on the shaft journal at different positions of the rotor.

15.3. Compensating Ability of Couplings

It is not so easy in practice to attain an absolutely accurate alignment of shafts which is one of the two essential requirements for a proper division of loads between the bearings.

That is why, the couplings of shafts being aligned have to be joined with a certain amount of misalignment.

Misalignment of shafts is such a mutual positioning of the latter in which the centre lines *1* and *2* being aligned are offset either sideways (radial displacement) or through a certain angle (axial displacement), as is illustrated in Fig. 15.3. The permissible radial and axial displacements for shafts primarily depend on the mechanical design and compensating ability of couplings employed.

Compensating ability is the ability of some couplings to compensate for a certain amount of misalignment of shafts

being coupled. Gear couplings of the M3 type are characterized by the highest compensating ability allowing for a radial displacement of shafts from 0.7 to 4.8 mm. The type МУВП peg-and-sleeve couplings allow for a radial displacement of 0.3 to 0.6 mm. The axial displacement allowed for by both these couplings is up to 1° or, when converted to

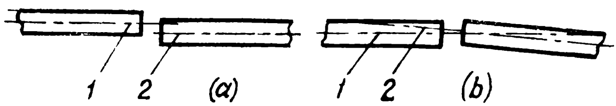


Fig. 15.3. Displacement of shafts
(*a*) radial; (*b*) axial

linear units, it makes up 3.5 mm for couplings having a diameter of 400 mm, 4.3 mm for those of 500 mm in diameter and 5.2 mm for couplings having a diameter of 600 mm.

Shafts joined via a flanged-face rigid coupling do not allow of radial or axial misalignment as they are to run as a single shaft. Hence, the alignment of such shafts is to be made with utmost accuracy, much higher than in the case of other types of coupling. When flanged-face couplings are used, axial clearances shall not exceed the following values:

For speed, r/min	3000	1500	750	500
Axial clearances, mm	0.04-0.05	0.08-0.11	0.1-0.12	0.15-0.20

15.4. Alignment Fixtures

Alignment fixtures are to be made on the site of installation or repair. In some cases they are made without a preliminary calculation, which is not the best way as an accurate alignment of shafts greatly depends on the construction of fixtures selected.

Table 15.1 specifies basic dimensions of alignment fixtures for selecting their sectional area (height h and width b) with the length being known.

Figures 15.4 and 15.5 illustrate alignment fixtures of different constructions. The fixture shown in Fig. 15.4*a* is used where the half-couplings are spaced at large distances. Its sectional area must be sufficient to ensure the desired

Table 15.1

Basic Dimensions of Alignment Fixtures

Design length of overhanging portion, mm	Sectional height h, mm	Sectional width b, mm	Design length of overhanging portion, mm	Sectional height h, mm	Sectional width b, mm
20	7	15	100	25	20
30	10	15	120	28	20
40	12	15	140	30	25
50	15	15	160	32	25
60	18	15	180	34	30
70	20	15	200	36	30
80	23	15	230	38	30

rigidity so as to prevent the displacement of the fixture end under the effect of its own mass or under the action of a feeler gauge used for measurements.

When the half-coupling rim is not provided with a threaded hole to receive the fastening bolt of the fixture, use shall

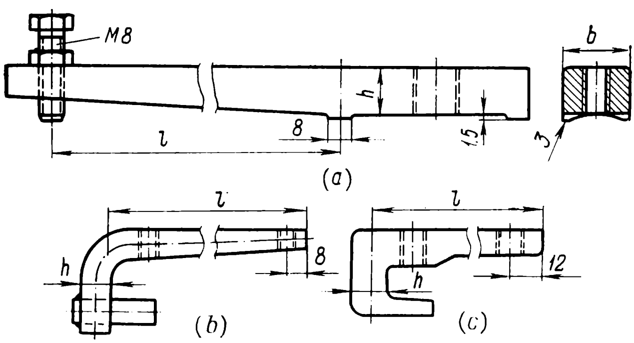
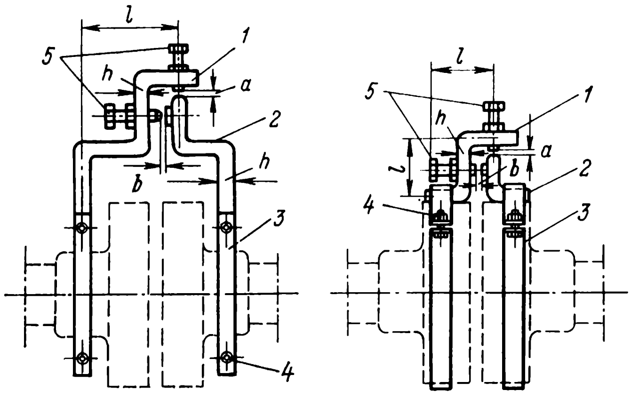


Fig. 15.4. Types of alignment fixtures

(a) fixture for half-couplings spaced at large distances; (b) fixture to be secured with a pin inserted in the bolt hole on the half-coupling; (c) fixture to be secured on the half-coupling rim

be made of a fixture illustrated in Fig. 15.4*b*. This fixture is fastened with a pin inserted in the hole for the half-coupling bolt. Fixtures secured on the half-coupling rim (Fig. 15.4*c*) have also found application.

Most widely used are alignment fixtures mounted on the half-coupling hubs (Fig. 15.5*a*) or directly on the shafts near the half-couplings. The alignment set comprises two fixtures *1* and *2* secured by means of clips *3* and bolts *4*. The fixtures and the clips are made of square steel. When in the working position, they are facing one another so that both



(*a*) (*b*)

Fig. 15.5. Alignment fixtures. General arrangement

(*a*) fixture to be mounted on the half-coupling hub; (*b*) fixture to be secured on the half-coupling rim; *1* and *2* — fixtures; *3* — clip; *4* — fastening bolts; *5* — metering bolts

radial *a* and axial *b* clearances can be checked at different positions of the shafts and, consequently, their half-couplings.

Figure 15.5*b* illustrates alignment fixtures *1* and *2* secured on the rims of half-couplings by means of clips *3* which are clamped together with bolts *4* and nuts.

15.5. Preparing the Shafts for Alignment

Prior to the alignment of shafts carry out the following preparatory jobs: make the working place ready for operation, check the shaft journals and the half-couplings for condition, prepare the latter for mounting, heat the half-couplings, mount them onto the shafts, clean and examine the bearing shells, check the shaft journals for proper arrangement in

the lower bearing shells, give the shafts a rough check for the alignment of their centre lines, check the shafts and half-couplings for radial runout and the half-couplings for end runout. All these operations are considered below in the same sequence, with the exception of the mounting procedure for half-couplings which has been already described in detail in Chapter Fourteen.

Making the working place ready for operation. Prior to starting the alignment of shafts, clean the working area and make it ready for this operation. To this end, remove all unnecessary bodies from the ends of the shafts to be aligned (heavy equipment handling outfit, tools, parts), clean the foundation and nearby surfaces of rubbish. Equip the working place with portable low-voltage lighting, bring and arrange in definite places all the necessary fixtures, ropes for turning the shafts with a crane, tools, and instruments. Make handy cylinder oil for lubricating the bearings, a notebook to enter the results of measurements, and a coloured pencil or chalk to apply markings on the half-couplings.

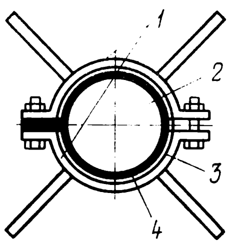


Fig. 15.6. Tool for grinding the shafts

1 — half-clip; *2* — shaft; *3* — felt spacer; *4* — sandpaper

Checking the shaft journals. From the shaft journals of machines delivered in a disassembled condition thoroughly remove slushing grease with clean rags moistened with petrol, white alcohol, or xylene. As an alternative, use can be made of wooden bars. Never use bars made of harder materials to prevent damage to the polished surfaces of the journals. Wipe the surfaces with a clean calico or gauze cloth moistened with ethyl alcohol. Then flush them in kerosene and wipe dry. Thoroughly examine the clean shaft journals.

If scratches, notches, or traces of corrosion are detected, grind the shaft journals with a tool illustrated in Fig. 15.6. Fit a piece of fine sand paper coated with oil on the shaft journal, then place a piece of felt over it and clamp the ends of the sandpaper and felt between the flanges of the half-clips so that they can be easily turned without applying much force. Turn the tool manually to grind the surface.

In the course of grinding change the sandpaper every 15 or 20 minutes and turn the rotor every hour through 90, 180, 270°, etc.

For polishing the shaft journals use the same tool adding crushed chalk to the oiled sandpaper. As an alternative, polishing can be made with the ГОИ paste diluted in kerosene and applied to a piece of pressboard or leather. Flush the polished shaft journals in kerosene and wipe them dry.

Checking the half-couplings for condition. Give the half-couplings the same treatment as the shaft journals, i.e. clean them of slushing grease first with wooden bars and then with rags moistened in petrol, white alcohol, or xylene. Then flush the half-couplings in kerosene, wipe them dry and examine for condition. If nicks, notches, or scratches are detected, thoroughly clean off the surfaces with emery cloth or a scraper.

Cleaning and examination of bearing shells. This operation is carried out when dealing with medium-size and large machines. First clean the bearing shells of slushing grease, flush in kerosene and examine them for pits, cracks, deep notches, or chipped white metal. To check for chipped white metal, keep the bearing in a bath with hot oil or kerosene for 24 hours, then wipe it dry and press on the white metal lining with your hand. Chipped white metal will be recognized by oil or kerosene squeezing out of the bearing shell joints. If the bearing needs scraping, make use of an air-operated scraper (see Chapter Six) for the purpose.

Checking the shaft journals for correct location in the lower bearing shells. Mount the shaft assembled with the rotor in the lower bearing shells and turn it several times. While doing so check the lower shells for possible misalignment by measuring the clearances between the shaft journal and the shell on either side of the shaft. Then check the shaft journal for location on the entire length of the bearing shell by inserting a feeler gauge on both ends of the shell. At the same time check the end play of the shaft in the bearings. Adjust the end play on both sides of the rotor central position determined by the magnetic field. The end play for machines having a shaft journal diameter of up to 200 mm shall be 2 to 4 mm and for those with a shaft journal diameter over 200 mm the end play shall not exceed 2 per cent the

shaft journal diameter on either side. The bearing shells are to be fitted to the journals after the shafts are aligned.

Rough alignment of shafts. Prior to coupling, check the shafts with half-couplings for end play and runout. The shafts are to be roughly aligned by observing the position of the half-couplings using a feeler gauge and a rule for the purpose. Place rule *1* on the rim of one half-coupling *2* (Fig. 15.7) and check with the feeler gauge radial clearance *a* and axial clearance *b*. Make such measurements at four points (at the ends of two mutually normal diameters of the half-coupling). If the shafts are aligned properly, the radial clearances *a* (for half-couplings of the same diameter) must be equal to zero and the axial clearances *b* must be equal to one another accurate to 0.01 mm per every 100 mm of the shaft diameter.

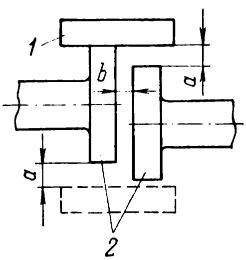


Fig. 15.7. Preliminary check of shaft centre lines for alignment by half-couplings

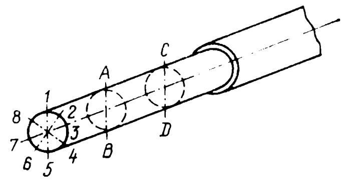
Checking the shafts and the half-couplings for radial runout. The shaft is to be checked for radial runout at a few planes over the shaft length. Divide the shaft circumference into eight equal sections and take measurements with a dial-and-indicator gauge placed on a rigid stand, the gauge measuring stem being in contact with the shaft surface. Before taking measurements, set the dial pointer to zero. Turn the rotor with a crane and put down the dial gauge readings at each of the eight positions of the shaft. The pointer deflection in one direction will give positive readings and in the other, negative readings. The shaft distortion relative to its centre line will give half its runout. To avoid errors, take two or three such measurements, every time shifting the dial gauge along the shaft axis. A recommended form to enter the results of measurement is presented in Table 15.2.

The maximum runout is determined by readings taken at diametrically opposite points where their difference is the greatest.

The radial runout is to be checked not only at the shaft journals but also at the points of installation of the bear-

Table 15.2

Measurements of Shaft Radial Runout



Section	Dial gauge readings at points								Maximum runout
	1	2	3	4	5	6	7	8	
A—B									
C—D									

ing seals and stator end shields, as well as near the rotor hub. For a shaft diameter of 100-200 mm the permissible radial runout of the shaft journal is not to exceed 0.02 mm and that for a shaft diameter over 200 mm it is not to be over 0.03 mm. At the surfaces on the shaft where bearing seals are fitted the runout is not to exceed 0.05-0.06 mm. The radial runout at

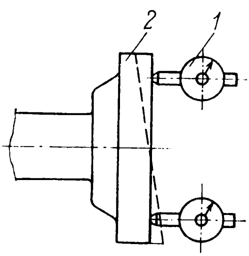


Fig. 15.8. Checking the axial runout of half-couplings

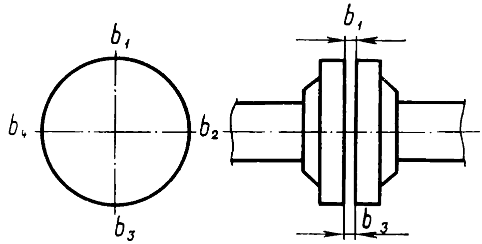


Fig. 15.9. Checking the axial runout of half-couplings by means of feeler gauges

other points (for high-speed machines) may be 0.15-0.20 mm. The radial runout of half-couplings is to be checked using the same technique. If the runout of the shaft exceeds the permissible values, apply to the Manufacturer.

Checking the half-couplings for end runout. Place two dial gauges *1* (Fig. 15.8) at diametrically opposite points on the butt end of half-coupling *2* at equal distances from the axis of rotation of the shaft. Divide the half-coupling circumference into an even number of equal parts (say, eight) and

determine the end runout from eight pairs of readings. To determine the end runout of the half-couplings, sum up the readings of both indicators taken at the same point on the half-coupling surface at two positions of the shaft, *viz.* before and after the latter has been turned through 180°. Then subtract the former sum from the latter one and halve the obtained difference.

If the distance between the half-couplings is too small to mount dial gauges, make use of feeler gauges and alignment fixtures for the purpose (Fig. 15.9).

With measurements made correctly the sum of clearances $b_1 + b_3$ shall be equal to $b_2 + b_4$ where b_1 and b_3 are the upper and lower clearances, respectively; b_2 and b_4 are side clearances between the surfaces of the half-couplings.

Example. At $b_1 = 1.77$ mm, $b_2 = 1.74$ mm, $b_3 = 1.72$ mm, $b_4 = 1.75$ mm, the sum of b_1 and b_3 (1.77 + 1.72) will be equal to the sum $b_2 + b_4$ (1.74 + 1.75) which means that the axial runout is absent.

According to Standard Specifications, measurements may be ceased at a difference between the mentioned sums not to exceed 0.03 mm. If the results are inadequate, repeat measurements without changing the position of the shafts and obtain the specified difference.

CHAPTER SIXTEEN

Alignment of Electrical Machine Shafts

The shafts of electrical machines can be aligned by a number of methods, as follows: alignment by means of a pair or two of radial-axial alignment fixtures, alignment by half-couplings, alignment by fixtures fitted with a flat or electromagnetic holdfast and dial gauges, alignment by a single-point runover method, alignment of machines with shafts supported on one end, alignment of electrical machine shafts with gear drive shafts, visual alignment by means of a centre locator, alignment of shafts of multimachine sets.

All these methods and tools involved are discussed below in mentioned sequence.

16.1. Alignment of Shafts by Means of a Pair of Radial-Axial Fixtures

This method is widely used in electrical machine installation practice.

Figure 16.1 illustrates the general construction of the radial-axial fixtures and shows how they are secured on the half-couplings.

External fixture *1* is secured on half-coupling *2* of the machine installed in position and internal fixture *3*, on half-coupling *4* of the machine to be coupled with the first one. The fixtures are secured by means of clips *5* and bolts *6*. In the course of alignment measure radial clearances a and axial clearances b by means of feeler gauges, indicator gauges, or micrometers. In the two latter cases, the indicator gauge or the micrometer screw head is to be inserted in the holes for bolts *7* and *8*.

Prior to taking measurements uncouple the half-couplings and set apart the shafts so as to prevent any contact between

the alignment fixtures and the half-couplings while the shafts are rotated. To obtain higher accuracy of measurements, set clearances *a* and *b* at minimum by means of bolts.

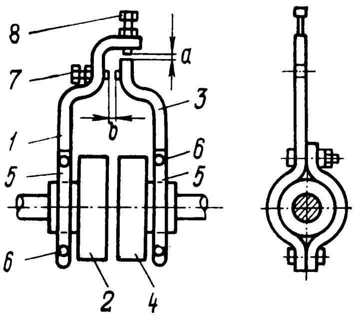


Fig. 16.1. Alignment of two-support shafts by one pair of radial-axial alignment fixtures

Irrespective of the method of alignment employed, the clearances between the butt ends of the half-couplings or those between the pointed ends of the radial-axial fixtures shall be measured with a feeler gauge so that the blades of the latter enter the clearance with an apparent friction through a depth at least two thirds their length (actually, through up to 20 mm). Since errors are inevitable in such measurements, their amount depending on the skill of the executive in charge, the results obtained shall be checked. With measurements made correctly, the sum of even-numbered measurements shall be equal to the sum of odd-numbered ones, i.e.

$$a_1 + a_3 = a_2 + a_4 \quad \text{and} \quad b_1 + b_3 = b_2 + b_4 \qquad (16.1)$$

In practice, however, the results of measurements may be considered as adequate if the difference between these sums is not over 0.03-0.04 mm.

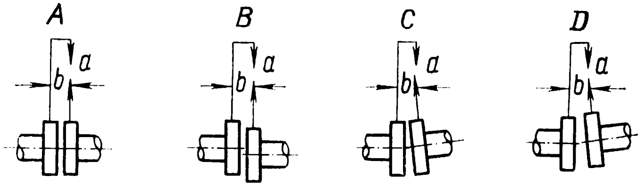


Fig. 16.2. Mutual setting of shafts

If this is not the case, make more thorough measurements without changing the position of the half-couplings. Fig. 16.2 shows four mutual positions of shafts being aligned.

At position *A* the shafts are lined up and their centres are in coincidence. It is evident that when such shafts are turned simultaneously, clearances *a* and *b* remain unchanged.

At position *B* the shafts are parallel but their centre lines are displaced from one another. When such shafts are rotated, the axial clearances *b* will remain unchanged while the radial clearances *a* will vary.

At position *C* the shaft centres are aligned but the centre lines form an angle. In such an event turning the shafts will change the axial clearances *b* while the radial clearances *a* will remain unchanged.

At position *D* the shaft centres are displaced and the centre lines form an angle. Turning these shafts will change both the axial, *b*, and radial, *a*, clearances.

Make the first measurement of clearances a_1 and b_1 with the alignment fixtures in the upper position. Then turn the shafts through 90° in the direction of rotation of the driven mechanism or machine and measure clearances a_2 and b_2 when the notches on the shafts are aligned. Make four such measurements, each time after turning the shaft through 90°. Then make the fifth (check-up) measurement after the alignment fixtures are again in the upper position. The results of the fifth measurement shall be equal to those of the first one.

In order to avoid errors, it will be a good practice to repeat measurements at the same positions of the shafts and by the same person.

The actual values of clearances *a* and *b* at the given point will be determined by a half-sum of corresponding clearances obtained by two measurements at the given point. The shafts shall be rotated manually or by a crane depending on the rotor mass. The shafts of small machines shall be turned manually without any tools.

For manually turning the shafts of large or medium-size machines use can be made of a special arrangement consisting of an arm *1*, a band *2*, and a band clamp *3* (Fig. 16.3).

The shafts of large electrical machines having a power output as high as 1000 kW and more still are to be turned with the aid of a crane (Fig. 16.4). To this end, wind machine shaft *1* with a few turns of a steel-wire rope *2* with loops *3* and *4* at the ends. Slip the loop *3* onto bolt *5* passing through

the hole in the half-coupling, attach the loop *4* to the crane hook and turn the shaft *1* by means of the rope *2*.

Prior to taking measurements (after the shafts are turned through the required angle) loosen the rope. To prevent the

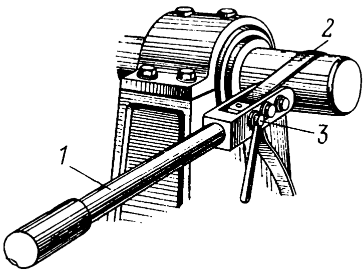


Fig. 16.3. Shaft turning tool for large or medium-size machine

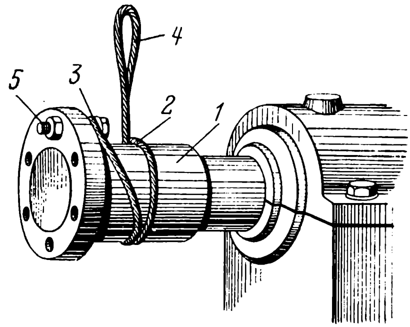


Fig. 16.4. Turning the large machine shaft by means of crane

half-couplings from setting apart or approaching one another while the shafts are turned, the latter shall be locked in position by means of special stop screws illustrated in Fig. 16.5.

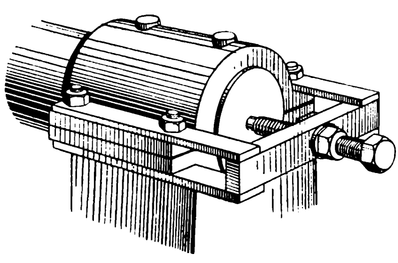


Fig. 16.5. Locking stop

When the shafts of a' motor-generator set are located close to the foundation and measurement of the clearance at the bottom of the half-couplings presents difficulty or is impossible at all it may be allowed to take measurements at three points, the clearance at the hard-to-get-at place being determined by calculation from the assumption that the sum of the upper and lower clearances equals that of the side clearances. In such an event the equation $b_1 + x = b_2 + b_4$ is constructed wherefrom we find the unknown clearance $x = (b_2 + b_4) - b_1$.

Substituting numerical values of side and upper clearances we can easily find the unknown bottom clearance.

Every time the shafts are turned through the required angle, measurements shall be taken only after the motor or bearing pedestal feet are reliably fixed to the bed plates to prevent

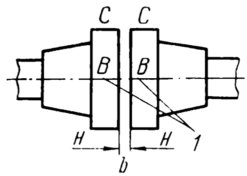


Fig. 16.6. Making notches on half-coupling rims to mark check points for feeler gauges

misalignment which may otherwise take place as the bolts are tightened up.

Clearances between the butt ends of half-couplings shall be measured with a feeler gauge at the same points. To this end, apply marks *1* at points shown in Fig. 16.6 using letters *C*, *H* and *B* to designate the top, bottom and side clearances.

Example. Figure 16.7*a* shows values of clearances (in mm) measured at four positions of the shafts. The radial clearances are put down beyond the circle and the axial clearances, inside the circle. Subscripts in designations of clearances a_1, a_2, a_3, a_4 show the serial numbers of measurements.

Figure 16.7*b* gives the dimensions (in mm) of the machine being coupled, *viz.* distance from the coupling to bearing *2* ($l_1 = 400$ mm), from the coupling to bearing *3* ($l_2 = 1800$ mm) and from the shaft centre line to bolt *4* ($r = 300$ mm).

In order to ensure a correct alignment of the shafts, bearings *2* and *3* of the machine being coupled (above 1000 kW) must be shifted over the bed plate or in the vertical plane by varying the number of shims under the bearing pedestals.

Let us introduce the following notation:

x_1 and x_2 denote a horizontal displacement of bearings *2* and *3* over the bed plate (Fig. 16.7*c*) to the right (indicated by sign "+") or to the left (indicated by sign "—"), as viewed on the butt end of the coupling from the side of the fixed machine;

y_1 and y_2 denote the vertical displacement of bearings *2* and *3* upwards (shown by sign "+") or downwards (shown by sign "—").

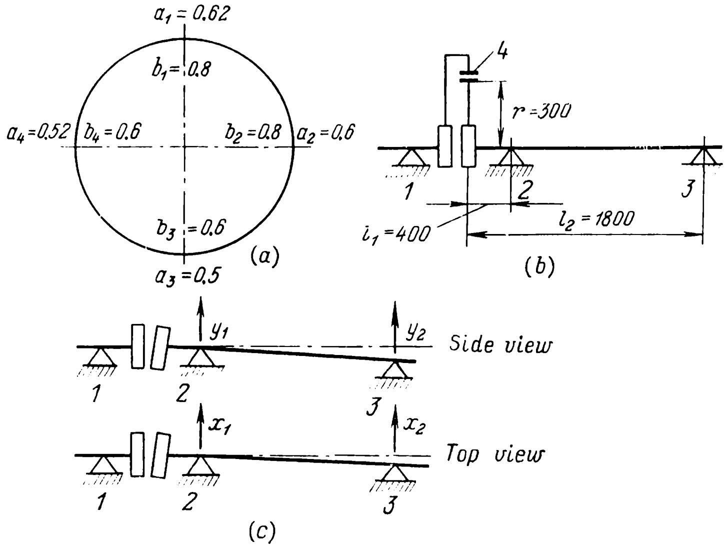


Fig. 16.7. Alignment of shafts by means of a pair of radial-axial fixtures (see example)
1-3 — bearings

The desired amount of displacement can be calculated using the following equations and substituting numerical values given in Fig. 16.7*a* and *b*:

$$y_1 = \frac{a_1 - a_3}{2} + \frac{b_1 - b_3}{2} \cdot \frac{l_1}{r} =$$

$$= \frac{0.62 - 0.5}{2} + \frac{0.8 - 0.6}{2} \cdot \frac{400}{300} = 0.19 \text{ mm} \tag{16.2}$$

$$y_2 = \frac{a_1 - a_3}{2} + \frac{b_1 - b_3}{2} \cdot \frac{l_2}{r} =$$

$$= \frac{0.62 - 0.5}{2} + \frac{0.8 - 0.6}{2} \cdot \frac{1800}{300} = 0.66 \text{ mm} \tag{16.3}$$

$$x_1 = \frac{a_2 - a_4}{2} + \frac{b_2 - b_4}{2} \cdot \frac{l_1}{r} =$$

$$= \frac{0.6 - 0.52}{2} + \frac{0.8 - 0.6}{2} \cdot \frac{400}{300} = 0.17 \text{ mm} \tag{16.4}$$

$$x_2 = \frac{a_2 - a_4}{2} + \frac{b_2 - b_4}{2} \cdot \frac{l_2}{r} =$$

$$= \frac{0.6 - 0.52}{2} + \frac{0.8 - 0.6}{2} \cdot \frac{1800}{300} = 0.64 \text{ mm} \quad (16.5)$$

Hence, the bearing *2* shall be raised by 0.19 mm and shifted to the right (sign "+") by 0.17 mm; the bearing *3* is to be raised by 0.66 mm and shifted to the right (sign "+") by 0.64 mm (Fig. 16.7*c*).

As can be understood from Fig. 16.7*a*, the sum of even-numbered measurements of horizontal and vertical clearances equals the sum of odd-numbered measurements. In fact,

$$a_1 + a_3 = a_2 + a_4 = 1.12 \text{ mm}; \; b_1 + b_3 = b_2 + b_4 = 1.4 \text{ mm}$$

Thus, the results of measurements can be checked by means of this equality. If the sums are unequal there is a sag in the alignment fixture or an axial displacement in the shafts which must be eliminated.

16.2. Alignment of Shafts by Means of Two Pairs of Radial-Axial Fixtures

When there is an axial displacement of shafts, i.e. when $a_1 + a_3$ is larger or smaller than $a_2 + a_4$ or $b_1 + b_3$ is larger or smaller than $b_2 + b_4$, it is recommended to align the shafts by means of two pairs of fixtures shifted 180° rela-

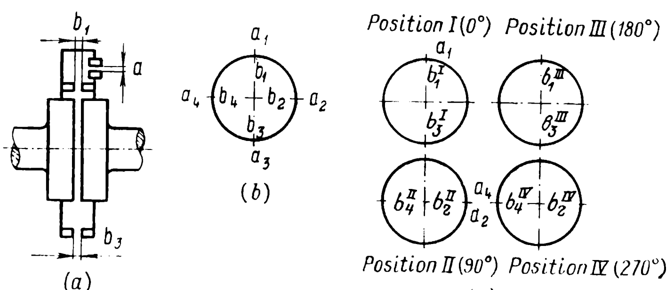


Fig. 16.8. Alignment of shafts by means of two pairs of radial-axial fixtures

tive to each other, as is shown in Fig. 16.8*a*. One of the pairs is to be used for measuring the radial and axial clearances and the other pair, for measuring the axial clearances only.

Both the pairs shall measure the axial clearances at an equal radius (distance from the centre line).

Like in the previous case, measurements shall be made at four positions of the shafts turned jointly through 0, 90, 180, and 270°.

Figure 16.8*b* illustrates this method and gives the lettering of clearances being measured. Fig. 16.8*c* shows four positions of shafts at which measurements are made. Hence, at position *II*, two axial clearances b_4^{II} and b_2^{II} as well as one radial clearance a_2 are measured; at position *III* measurements are taken of axial clearances b_1^{III}, b_3^{III} and radial clearance a_3, etc. Then the resultant values of axial clearances are to be found as a half-sum of two axial clearances measured at one point first by one pair of fixtures and then by the other,

$$b_1=\frac{b_1^{I}+b_1^{III}}{2}; \qquad b_2=\frac{b_2^{II}+b_2^{IV}}{2}$$

$$b_3=\frac{b_3^{I}+b_3^{III}}{2}; \qquad b_4=\frac{b_4^{II}+b_4^{IV}}{2} \tag{16.6}$$

The required amount of displacements y_1 and y_2, x_1 and x_2 shall be found from equations (16.2) through (16.5) replacing the letters b_1, b_2 and b_3, b_4 by the numerical values of these axial clearances.

Example. Let us assume that the distance from bearings *3* and *4* (see Fig. 16.7*b* and *c*) and that from the shaft to bolt *5* are the same as in the example given in the previous section, and measurements were made with two pairs of radial-axial fixtures, the axial clearance (see Fig. 16.8) being as follows:

$$b_1^{I}=0.47\ \text{mm} \quad \text{and} \quad b_3^{I}=0.52\ \text{mm}$$

$$b_2^{II}=0.44\ \text{mm}; \qquad b_4^{II}=0.67\ \text{mm}$$

$$b_1^{III}=0.49\ \text{mm}; \qquad b_3^{III}=0.54\ \text{mm}$$

$$b_2^{IV}=0.54\ \text{mm}; \qquad b_4^{IV}=0.71\ \text{mm}$$

The resultant values of axial clearances b_1, b_2, b_3, b_4 will be determined as a half-sum of axial clearances measured at the same

point by one pair of fixtures and then by the other. Hence,

$$b_1=\frac{b_1^{\mathrm{I}}+b_1^{\mathrm{III}}}{2}=\frac{0.47+0.49}{2}=0.48 \text{ mm}$$

$$b_2=\frac{b_2^{\mathrm{II}}+b_2^{\mathrm{IV}}}{2}=\frac{0.44+0.54}{2}=0.49 \text{ mm}$$

$$b_3=\frac{b_3^{\mathrm{I}}+b_3^{\mathrm{III}}}{2}=\frac{0.52+0.54}{2}=0.53 \text{ mm}$$

$$b_4=\frac{b_4^{\mathrm{II}}+b_4^{\mathrm{IV}}}{2}=\frac{0.67+0.71}{2}=0.69 \text{ mm}$$

The amount of displacements y_1, y_2, and x_1, x_2 for the given case will be found from equations (16.2) through (16.5) substituting in them the resultant values of clearances b_1, b_2, b_3, and b_4.

16.3. Alignment of Shafts by Half-Couplings

Figures 15.4*c* and 16.9 illustrate one of the type varieties of fixtures used for the alignment of shafts by half-couplings. Inserted in the alignment fixture is a metering bolt with a lock nut (or an indicator gauge). Radial clearances *a* shall be measured with a feeler gauge inserted between the metering bolt and the external surface of the half-coupling. Axial clearances *b* are to be checked between the butt ends of the half-couplings.

One radial clearance and two or four axial clearances are to be measured at every of the four positions of the half-couplings (0, 90, 180, 270°). The average values of axial clearances obtained from several measurements are to be determined as an arithmetic mean by dividing the sum of clearances by the number of measurements (two or four).

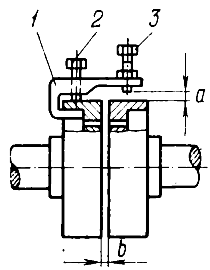


Fig. 16.9. Alignment of shafts by half-couplings

1 — alignment fixture; *2* — bolt; *3* — metering bolt

The amount of displacements y_1, y_2 and x_1, x_2 shall be found from equations (16.2) through (16.5) substituting in them the numerical values of axial clearances b_1, b_2, b_3, and b_4.

It shall be borne in mind, when using this method of alignment, that rigid couplings having movable joints (such as geared couplings) may be aligned with a lower accuracy than flexible couplings. That is why before taking measurements at such half-couplings make sure that there is no seizure at the movable joints. To this end, use a lever to check for free angular displacement of jointed parts in either direction.

16.4. Alignment of Shafts with the Aid of Fixtures Having a Flat or an Electromagnetic Holdfast

The fixtures furnished with a flat or an electromagnetic holdfast (Fig. 16.10*a* and *b*, respectively) are similar in construction. With such fixtures measurements can be made both by dial gauges and feeler gauges.

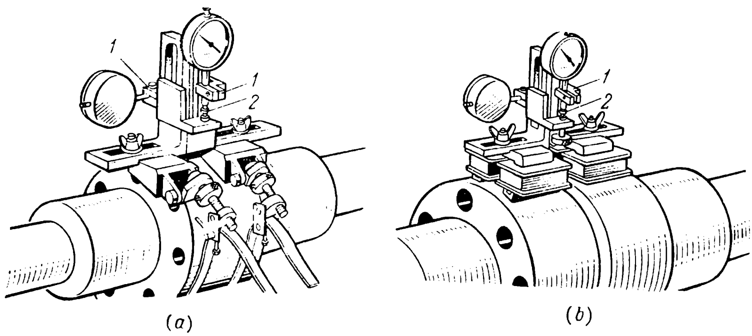


Fig. 16.10. Alignment fixtures with flat (*a*) and electromagnetic (*b*) holdfasts

The flat holdfast is simple in construction which can be easily understood from Fig. 16.10*a*.

The electromagnetic holdfast fixtures consist of two U-shaped electromagnets supplied with power from flashlight batteries and furnished with hinged pole shoes which hold the fixtures in position on the half-couplings of the shafts being aligned. The pole shoes are suitably shaped to ensure their tight fitting to the rims of the half-couplings of any diameter.

Setting two dial gauges directly on the fixture makes it possible to take measurements in the horizontal and vertical planes simultaneously and with a higher accuracy than in the case of measurement by dial gauges secured on stands when the metering stem comes in contact with the rough machined surface of a half-coupling rim or butt end. If dial gauges are not available, measurements can be made with a feeler gauge. To this end, fit a metering stem similar to adjusting screw *2* in dial gauge holder *1*.

The measurement accuracy will be higher at larger diameters of half-couplings.

When measurements are made with a feeler gauge, the blades of the latter shall enter the clearance through a depth of not over 20 mm and with a certain amount of friction.

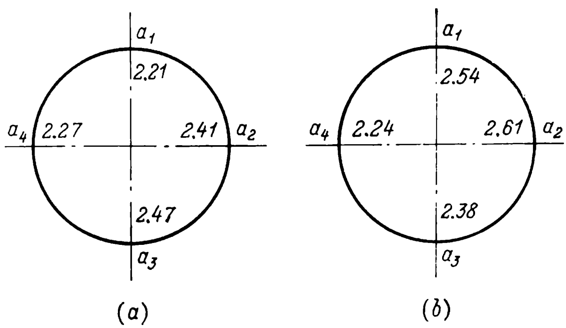


Fig. 16.11. Typical measurements in the alignment of shafts

Since errors are inevitable in measurements taken with a feeler gauge, the degree of errors depending on the skill of the executive in charge, the results obtained must be checked, bearing in mind the following: if measurements were made accurately, then the sum of clearances between the surfaces of the half-couplings, as measured at their top and bottom, i.e. $a_1 + a_3$, must be equal to the sum of axial clearances $a_2 + a_4$ (Fig. 16.11); moreover, the difference of these sums must not exceed 0.03 mm.

If this is not the case, measurements shall be repeated and made more thoroughly at the same position of the half-couplings.

Example. The shafts are located in a position characterized by measurement results given in Fig. 16.11. For measurements presented in Fig. 16.11*a* the results will be

$$\text{(a)}\quad a_1 + a_3 = 2.21 + 2.47 = 4.68 \text{ mm}$$
$$a_2 + a_4 = 2.41 + 2.27 = 4.68 \text{ mm}$$

which shows that measurements were made correctly as

$$a_1 + a_3 = a_2 + a_4$$

For measurements shown in Fig. 16.11*b* the results will be as follows:

$$\text{(b)}\quad a_1 + a_3 = 2.54 + 2.38 = 4.92 \text{ mm}$$
$$a_2 + a_4 = 2.61 + 2.24 = 4.85 \text{ mm}$$

Measurements were made incorrectly as $a_1 + a_3$ is not equal to $a_2 + a_4$.

For case (a) where measurements were made properly one of the shafts has an angular displacement relative to the other in two directions, i.e. the bottom clearance a_3 between the half-couplings is larger than the top clearance a_1, and the left-hand side clearance a_2 is larger than the right-hand clearance a_4 (Fig. 16.11*a*). Consequently one of the bearings must be lowered to reduce the bottom clearance a_3 between the half-couplings by

$$\frac{a_3 - a_1}{2} = \frac{2.47 - 2.21}{2} = 0.13 \text{ mm}$$

The same bearing must be displaced sideways to reduce the side clearance a_2 by

$$\frac{a_2 - a_4}{2} = \frac{2.41 - 2.27}{2} = 0.07 \text{ mm}$$

In this way equal clearances will be obtained on the top and at the bottom.

16.5. Alignment by Single-Point Runover Method

When one of the shafts cannot be rotated during alignment, clearances between the butt ends of the half-couplings can be checked with only one shaft turned. A special fixture *2* secured to the half-coupling of turning shaft *1* (Fig. 16.12) shall be used for the purpose. As an alternative, measurements can be made by means of alignment fixtures illustrated in Fig. 15.4*b* and *c*. Such a method is known as a single-point runover method.

With this method the sideways displacement is checked by measuring the clearance between pin *4* of the fixture *2* and the rim of a half-coupling *5* mounted on a motionless shaft *6*. Measurements are to be made with a feeler gauge *7*. Axial

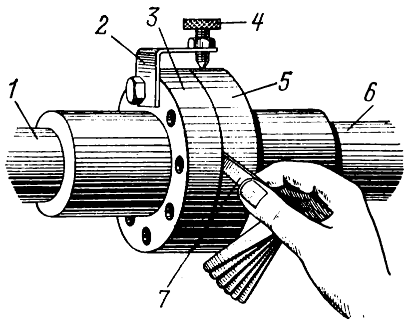


Fig. 16.12. Alignment of shafts by single-point runover method

displacement is to be checked by measuring the clearance between the butt ends of the half-couplings *3* and *5* with the aid of the feeler gauge *7*.

In mounting electrical machines of an output power exceeding 500 kW it may be necessary to align machines having a single-support shaft or to couple the machines with gear drive mechanisms. Some recommendations on the subject are given below.

16.6. Alignment of Single-Support Shafts

When a single-support shaft is to be lined up, it shall be supported on one end on the pre-levelled bearing and on the other end it is to be arranged so as to let the spigot of one half-coupling fit into the recess on the other half-coupling. Such a connection is known as a solid-forged coupling which has been described in Chapter Fourteen and illustrated in Fig. 14.1*a*.

Hence, the single-support shaft being lined up rests on the half-coupling ring on one end and on its own bearing on the other end. A small clearance of 1-2 mm is left between the butt ends of the half-couplings. For the period of align-

ment the half-couplings are bolted together, the diameter of these bolts being somewhat smaller than that of the half-coupling bolts. The bolts are to be accurately fitted to the holes in the half-couplings. Alignment is made by the half-couplings just as in the case of two-support shafts. The distances for necessary displacements are to be calculated by using the same equations as in the case of alignment of two-support shafts with the aid of a single pair of alignment fixtures.

The aligned shafts shall be checked again after this procedure is over as distortions and misalignment may appear as a result of a non-uniform tightening of bolts, rough finish of the butt ends of the half-couplings, etc.

To this end, mount two dial gauges on the journal of the single-support shaft, one being set in the vertical plane and the other, in the horizontal plane. Fix the dial gauges *in situ* to the bearings and take readings of the dial gauge installed in the vertical plane. Then raise the end of the shaft using a tool illustrated in Fig. 16.13, remove the lower bearing shell and return the shaft end to the original position. The dial gauge mounted in the vertical plane must give the same reading. Turn the rotor through 0, 90, 180, and 270°. Measure the runout of the shaft ends by means of the dial gauge installed in the horizontal plane.

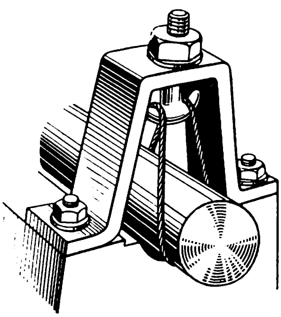


Fig. 16.13. Tool for lifting the shafts of large and medium-size machines to a small height

The amount of runout of the shaft end shows whether the shafts are aligned and the half-couplings joined correctly.

If Manufacturer's Standard Specifications are not available, refer to the following permissible runout values specified for different speeds of machines:

Speed, r/min	1000	1000-1500	1500-3000
Permissible runout for shaft, mm	0.15-0.20	0.12-0.15	0.05-0.08

16.7. Alignment of Electrical Machine Shafts with the Shafts of Gear-Driven Machines

This section deals with the alignment of the shafts of drive motors with those of reduction units. In this case the fixed item is the reduction unit and the drive motor is lined up with the former. In the action, it shall be taken into account that when the reduction unit is running, the shaft of

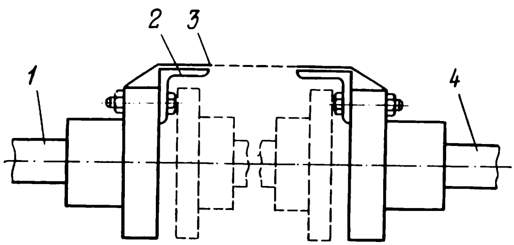


Fig. 16.14. Alignment of shafts coupled via an intermediate shaft

the driving wheel usually goes up over a distance equal to the vertical clearance in the bearings. That is why, the electrical machine shaft shall be set higher than the gear wheel shaft by the length of this vertical clearance.

In practice, shaft *1* of the drive motor can be coupled with shaft *4* of the reduction unit via an intermediate shaft having no bearings (Fig. 16.14).

Such a type of connection may be encountered, for instance, in rolling mill stands whose reduction units are coupled with the drive motors in this way.

As the length of the intermediate shaft may reach 1.5 or 2 m, it may happen that the alignment of the motor and reduction unit shafts cannot be checked with a feeler gauge, dial gauge or some other measuring instrument. In such an event the alignment of shafts can be made by a rather simple and reliable method using specially constructed angle plates *2* and a stretched wire *3*.

The outer surfaces of each angle plate must form a right angle. The angle plates are to be fixed with one side to the butt ends of the half-couplings and the other side of these plates is to be used for stretching a thin steel wire along

it. With the stretched wire and the angle plates it will be possible to measure the axial and radial displacements of the motor and reduction unit shafts. The angle plates are secured to the half-couplings and the stretched wire is tensioned with the aid of bolts and nuts. In selecting the bolt diameter and in tightening the nut it shall be taken into account that even a slight displacement of bolts in the holes of the half-couplings during the rotation of shafts may cause errors in measurements with the result that the alignment will be inadequate.

16.8. Visual Alignment of Shafts by Means of Centre Locator

A correct marking-out of half-couplings over an arc of 90° on their circumference to determine diametrically opposite points of measurements is a decisive factor ensuring the desired measuring accuracy in the alignment of shafts.

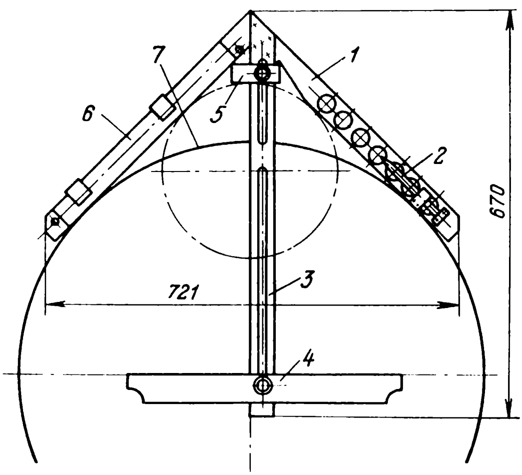


Fig. 16.15. Centre locator

For machines rotating at a speed of up to 1000 r/min this marking-out may be carried out visually, accurate to ±30′, with the aid of a straightedge.

A device incorporating a straightedge and termed a centre locator has been developed and used for the purpose since 1972.

The centre locator illustrated in Fig. 16.15 is intended for visual marking-out of the points of measurement with an accuracy of $\pm 30'$ in the alignment of shafts with half-couplings *7* having a diameter of 350 to 700 mm. The centre locator consists of a try-square *1*, a marking rule *3*, a straight-

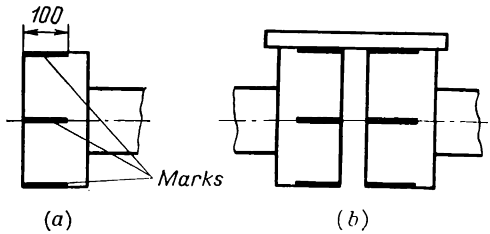


Fig. 16.16. Marking-out of the outer surfaces of half-coupling rims (*a*) and alignment of shafts with a straightedge against marks applied by means of a centre locator (*b*)

edge *6*, a slider *4* with a locating rule, a slider *5*, and a marking tool *2*.

The centre locator serves to divide the half-coupling circumference by applying marks spaced $90° \pm 30'$ apart on its outer surfaces. The procedure is as follows:

set the try-square *1* of the centre locator on the half-coupling *7* so that the marking rule *3* lies on the butt end of the half-coupling, and draw a mark on the face of the latter by means of the marking tool *2*;

turn out the screw of the slider *5* on the marking rule *3* half the revolution and move the slider over the straightedge. Fix the slider in position and draw marks on the butt end of the half-coupling and on the outer surface of its rim by means of the marking tool;

turn the centre locator through 90°. To check for accurate turn through this angle, align the slider with the locating rule *4* against the mark drawn during the previous procedure on the half-coupling face; lock the slider in position and draw marks on the butt end of the half-coupling and on the outer surface of its rim.

By turning the centre locator in this way, draw all the four marks on the outer surface of each half-coupling (Fig. 16.16*a*).

The shafts are to be aligned by means of the straightedge with reference to the marks drawn on the outer surfaces of the rims of both half-couplings by means of the centre locator (Fig. 16.16*b*).

16.9. Alignment of Shafts of Multimachine Sets

Proper alignment of shafts is particularly important in the installation of multimachine sets of rolling mills which may consist of as many as five electrical machines. Low-speed motor-generator sets comprising three or five machines employ standard synchronous motors as driving machines. The

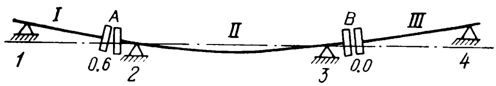


Fig. 16.17. Alignment of a three-machine set
I, *III* — generators; *II* — drive motor

bearings of these motors are not designed to take the additional loads due to the mass of the generator armatures which are supported by a single bearing only.

In order to relieve the drive motor bearings of loads imposed on them by the mass of the generator armatures a new method has been introduced for the alignment of shafts of such motor-generator sets.

This method consists in that the uniform distribution of loads on all the bearings is attained by an appropriate arrangement of some shafts at which the faces of their half-couplings are set at a certain predetermined angle. Fig. 16. 17, for instance, illustrates the shaft line of a three-machine set composed of a synchronous motor and two dc generators meant to feed a blooming mill. The Manufacturer put forward an idea that the shaft line of these machines had an angular clearance of 0.6 mm between the mating faces of half-couplings at joint *A* and the faces at point *B*

were parallel. The Manufacturer also specifies permissible loads on the bearings of these machines which are found by calculation.

The machines of such sets are usually delivered to the installation site in a disassembled condition. Prior to starting the alignment of the shafts of multimachine sets, mount and level off the bed plates, tighten up the anchor bolts, mount the bearing pedestals, the stators, and lower half-frames, drive the rotors (or armatures) into the stators. In addition to that, do the following:

familiarize yourself with the Manufacturer's sketch of the motor-generator set showing the serial numbers of machines, bearings, and half-couplings or flanges as well as the permissible loads on the bearings and the angular clearance for the mating surfaces of the half-couplings or flanges. Also obtain design data on the alignment of the shaft line from the Manufacturer's Standard Specifications;

check the bearing load test equipment for condition (Fig. 16.18) and make sure that hoisting and haulage facilities available on site are suitable for the job. Bear in mind that the mass of every

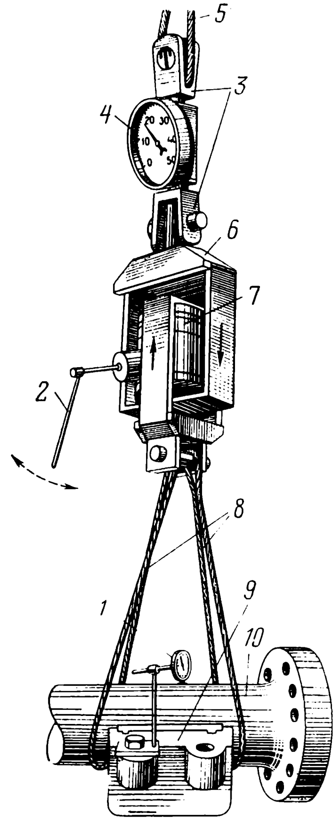


Fig. 16.18. Arrangement for determining the loads on bearings of multimachine sets by weighing method

1 — dial gauge; *2* — hydraulic jack operating handle; *3* — dynamometer shackles; *4* — dynamometer; *5*—steel-wire rope sling (for overhead travelling crane); *6* — smooth-lifting hoist; *7* — hand-operated hydraulic jack; *8* — multipurpose steel-wire rope sling; *9* — bearing pedestal; *10* — rotor (armature) shaft

shaft assembled with the rotor or armature shall not exceed the load-carrying capacity of the crane;

determine the cross-sectional area of slings and select them to suit the maximum load on the bearing being tested when weighing the shaft portion with the rotor or armature.

In order to align the shafts of a motor-generator set in compliance with the design data, proceed as follows:

measure the angle of inclination of the shaft journals of the central machine which is supported by two bearings and adjust them so that these shaft journals be equally elevated from the horizontal plane. Level off and secure in position the bearing pedestals of this machine;

line up the shaft of one of the single-bearing machines with that of the central machine. To this end, check the size of the spigot on one half-coupling or flange for compliance with that of the recess on the other half-coupling, insert the spigot into the recess, measure and adjust the clearance between the faces of the half-couplings or flanges, set and turn in auxiliary bracing bolts;

line up the shaft of the other machine with the opposite end of the shaft of the central machine; proceeding in the above-described sequence, line up the shafts of all the machines incorporated in the set;

check the half-couplings or flanges for a rigid connection provided by auxiliary bolts and the bearing pedestals for a reliable fixation in position;

suspend a dynamometer, complete with a smooth-lifting hoist, from the hook of a travelling crane (see Figure 16.18);

remove the bearing caps and upper shells and secure the dial gauge on the pedestal of the bearing being tested;

suspend shaft portion *10* being weighed from the dynamometer secured on the smooth-lifting hoist;

carefully lift the crane hook carrying the shaft till the slings are tensioned and the dynamometer pointer starts deflecting;

keep lifting the shaft by means of a hand-operated hydraulic jack installed between the shackles of the hoist till the dial gauge pointer makes a deflection through one or three divisions to indicate that the shaft has come off the

bearing shell. Put down the dynamometer and dial indicator readings at this very moment;

using the hydraulic jack, carefully move the shaft down till the dial gauge pointer makes a deflection through one or three divisions and write down the readings of the dial gauge and the dynamometer again;

compare the actual loads on bearings with the design data. Proceeding in the same sequence, determine the actual loads on the remaining bearings;

if some of the bearings take more than their share, re-distribute the loads on bearings by appropriately varying the height of the bearing pedestals;

draw up a report on the results of the load distribution test;

undo the nuts of the auxiliary bolts and measure the clearances between the mating surfaces of the half-couplings or flanges again;

compare the results of these measurements with the first ones complying with design data;

remove the shaft from the hoist and the latter from the travelling crane hook;

install the upper bearing shells and the bearing caps in their original positions;

replace the auxiliary bolts on the half-couplings by permanent bolts one after another.

16.10. Alignment Tolerances

The radial and axial clearances, as measured after alignment by alignment fixtures, 250-300 mm long, with the rotors jointly turned through 0, 90, 180 and 270° (or 0, 120 and 240°), shall not differ by more than 0.03 mm. For other lengths of alignment fixtures, the tolerances change in proportion to these lengths.

In the case of alignment by half-couplings, the radial and axial clearances at the same positions of the shafts (for couplings having a diameter of 400 to 500 mm) shall not differ by more than 0.05 mm.

The permissible runout of the shaft extension is usually specified by the Manufacturer and depends, as has been stated above, on the electrical machine speed.

16.11. Final Alignment of Shaft Lines

For the final alignment of the shafts of medium-size and large electrical machines the rotor can be shifted upwards, downwards and sideways within a short distance (to avoid the disturbance of the shaft proper fitting in both the lower bearings) by displacing the bearing pedestals. It shall be borne in mind that with such a displacement of pedestals together with the rotor inserted in the stator the displacement of the latter is indispensible, so as to retain the specified air gaps between the stator and rotor cores.

The rotor position can be adjusted by moving the bed plate. A great number of temporary shims may appear under the bed plate and the bearing pedestals as a result of repeated displacements of these parts. After the proper alignment is attained, these shims shall be replaced by permanent ones made to fit the sizes of the former.

The shims are to be replaced one by one at every point to prevent deformation of the bed plate which may take place if all the shims are knocked out simultaneously. Prior to replacing the temporary shims, mark the points of their installation on the bed plate. Fit the permanent shims with reference to these marks by lightly tapping them with a hammer. The shims shall be fitted rather tightly, but without loosening the already installed ones. To this end, in the process check the clearances with a feeler gauge and sound out by tapping the shims, both newly installed and the neighbouring ones, with a hammer.

Then check the anchor bolts and the fastening bolts of pedestals for reliable tightening and correct positioning, whereupon skip-weld the anchor bolt nuts to the bed plate, bolt together the rigid half-couplings and finally check out the alignment and the air gaps between the stator and rotor cores.

Also make sure that the rotor does not brush against the stator end shields. To this end, carry out a trial installation of the stator end shields when dealing with medium-size and large electrical machines. If the rotor brushes against the end shields, increase its axial play by axially moving the bearings. This done, fit taper check pins in the bearing pedestals and stator feet by driving them in with a lead or

other hammer (two pins per pedestal and stator). While the holes of mating parts are not yet checked, set non-insulated pins so as to avoid damage to insulation. After the holes have been checked out, drive in insulated pins. Then enter data on the alignment, on air gaps between the stator and rotor cores, clearances in bearings, inclination of shaft journals, etc. in the machine certificate.

16.12. Assembling, Alignment, and Connection of Couplings

These operations are to be carried out after the shafts are fully aligned. Prior to connecting the machines with rigid or semi-flexible couplings examine the mating surfaces of the latter for dents, scratches, burrs, and other defects. Then ream out the roughly drilled holes to receive fastening bolts. Before doing this, brace the half-couplings together by auxiliary bolts so as to ream out the holes in the two half-couplings simultaneously. Then check the radial runout of every half-coupling before and after driving in all the fastening bolts by taking measurements at four points spaced 90° apart. If the runout exceeds the alignment tolerance as a result of inaccurate reaming, then ream out the holes to a larger diameter and replace the fastening bolts with thicker ones.

After assembling check the movable joints obtained in gear couplings for axial displacement of shafts which may take place as a result of thermal expansion; also make sure that specified clearances are provided between the caps and the butt ends of the hub teeth as well as between the butt ends of the hubs (see Fig. 14.1*a*). In gear couplings check, in addition, the gear clearance and tooth pitch which shall be accurate to ± 0.05 mm.

When assembling Bibby couplings, check the slots between the teeth of half-couplings for equal dimensions and the springs for axial displacement. Besides, make sure that the springs are not jammed.

In assembling peg-and-sleeve flexible couplings check the diameters of rubber or leather packings and holes for their fixation. In the action, make sure that the flexible portions

of the pegs easily enter the holes (the difference in diameters may be as large as 2 or 4 mm). Clearances of 5 to 8 mm may be allowed between the mating surfaces of the half-couplings.

In assembling and aligning these half-couplings it is essential that the flexible portions of all the pegs in the driven half-coupling should fit the surfaces of the holes over the entire length. To check the pegs for a correct position, proceed as follows: after having installed each peg, check the half-couplings for mutual displacement by lightly rocking one of the rotors in either direction. In the action obtain an equal displacement for all the pegs. No displacement in setting any one of the pegs points to improper installation or finishing of the peg, or to incorrect dimensions of the driven half-coupling bore.

16.13. Grouting the Bed Plates and Anchor Bolts in Concrete

After a machine is installed in position, accepted in accordance with the report, aligned with the driven mechanism or other electrical machines incorporated in the motor-generator set, the bed plates must be grouted in a concrete compound. This procedure is to be carried out by the building contractor under the supervision of the electricians. Prior to applying the grouting compound, the foundation surfaces to be grouted must be notched; the surfaces where old concrete is expected to come in contact with the grout shall be thoroughly cleaned of oil, kerosene, and other materials and continuously moistened for a few days before the application of grout. The machine may be started not earlier than 10 or 15 days after grouting (at a normal temperature of hardening).

When grouting in concrete is to be made in winter time at an average daily temperature below 5° C and a minimum daily temperature below zero, this work shall be carried out in compliance with the instructions set forth hereunder.

The concrete grout applied in cold seasons shall be heated with electric current to the following maximum temperatures depending on the type of cement and grade of concrete:

Type of cement	Grade of concrete	Concrete temperature, °C
Portland blast-furnace	300	40-80
Portland puzzuolanic	300	45-80
Portland	300-400	45-70
Portland	500	35-40

An important factor in grouting the bed plates and anchor bolts in concrete at sub-zero temperatures is fast hardening of the grout. High-grade portland cements (grade 500 and higher) are most suitable for the purpose.

The intensity of cooling the grout at electric heating is adjusted by varying the supply voltage or periodically switching off the power supply. The grout must be free from pieces of ice, snow, and frozen cement. To accelerate hardening of concrete in winter time, chemical additives, such as calcium chloride, sodium chloride, or ammonium chloride, are introduced. The total amount of chlorides must not exceed 7 per cent of cement mass (including anhydrous salts) or 15 per cent of the amount of mixing water. The required amount of additives is to be determined each time in accordance with pertinent instructions.

CHAPTER SEVENTEEN

Fitting the Bearing Shells and Assembling the Bearings

Construction of sleeve bearings. Large electrical machines have pedestals fitted with sleeve-type bearings (see Chapter One). Medium-size and some large machines are equipped with antifriction (ball and roller) bearings.

The pedestal sleeve bearing consists of a pedestal, a cap, bearing shells and labyrinth seals of the shaft. The bearing cap and the pedestal have a cylindrical groove to receive the self-aligning ring. The bearing cap is secured to the pedestal with four bolts. A special retainer is provided on the top of the cap to prevent the displacement of shells while the shaft is rotating. The retainer has a through hole to admit lubricating oil to the bearing. The pedestal and the cap are cast-steel structures. The pedestal accommodates the bearing shell which has a split along the horizontal plane.

The bearing shells are usually made of cast iron for machines subject to shock loads (such as rolling mill motors) or cast of steel for large turboalternators. The interior of the bearing shells is lined with white metal (babbit lining). Grade Б-83 babbit is most suitable for machines with a peripheral speed of the shaft journals from 10 m/s and higher while grade Б-16 babbit is to be used for those having a lower peripheral speed. The two halves of the shells are bolted together and two check pins or precision bolts are fitted diagonally.

The cast-iron labyrinth seals are secured to the bearing cap and pedestal on both end faces. The seals are split along the horizontal plane. The two halves of the labyrinth seal are bolted together. To ensure a tight fit between the labyrinth seal and the shaft, brass plates are press-fitted into the labyrinth housing.

The bearings are distinguished according to the method

of oil delivery to the rubbing surfaces of the shaft and shells as (*a*) ring-lubricated and (*b*) those lubricated by oil circulation. Ring lubrication is afforded by oil rings loosely fitted on the shaft journals. The oil ring rotates together with the shaft and feeds oil from the oil tank to the shaft journal. Two oil rings are provided for long bearing shells.

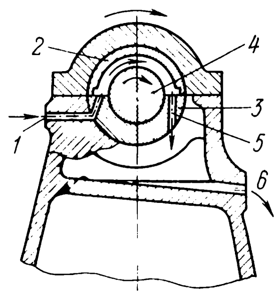


Fig. 17.1. Oil circulation system for bearings lubricated by circulating oil

The oil circulation system for bearings lubricated by circulating oil is illustrated in Fig. 17.1. Oil is passed under a pressure of 0.25 to 0.5 kgf/cm^2 through hole *1* in the bearing pedestal and delivered to a gap provided between the bearing shell and the shaft journal at its split joint over the entire length, wherefrom the largest portion enters the space between upper shell *2* and the journal and the smaller portion goes to lubricate lower shell *3*.

Oil drain is effected through hole *5* into the bearing housing and then through hole *6* into the drain pipe of the oil pipeline.

Particles of oil settled on the rotating shaft journal carry away adjacent particles due to their adhesive force with the result that a pressure is created which forces the journal to go up and away from the bearing shell. Shaft *4* floats up and in this way a lubricating layer is formed between the rubbing surfaces.

The lubricating layer increases with the shaft speed. When motionless, the shaft rests with its journals on the bearing shells. That is why, at the initial moment of starting there is the so-called metal-to-metal (dry) friction between the shaft journal and the shell. As the machine is started, oil particles carried away by the rotating shaft journal create a wet friction between the latter and the bearing shell. The time and amount of dry friction depend on the machine size and conditions for its acceleration.

The dry friction causes wear of the bearing shell surfaces and, besides, increases the drag torque of the machine. That

is why, large machines running under heavy starting conditions and requiring a long time to gain speed are equipped with special pumps which operate during the starting period to force oil to the bottom of the bearing shell.

Owing to such an arrangement the shaft journal floats up at the moment of starting as soon as an oil layer is formed.

Fitting the bearing shells. While the machine is running, its bearings heat up, the causes of this being of different nature. One of them is the condition and area of the lower shell rubbing surface. The greater the rubbing surface, the lower is the specific pressure per unit area and, hence, the less is the amount of heat liberated in the bearing during the machine running

Electrical machines subjected to a pre-installation assembly and test at the manufacturing plant and having their shafts thoroughly aligned do not usually need fitting the bearing shells in the course of installation. It may happen, however, that the Manufacturer did not give much consideration to the alignment of bearings when assembling the machine. In such cases, the surfaces of the bearing shells must be finished on the site of installation. The finishing procedure consists in scraping the bearing surfaces of the shell so that the latter could bear on the shaft journal with its greater portion. A bearing shell may be considered as properly fitted if after checking by blueing two or three marks per 1 cm^2 area over an arc of 60-120° appear on its surface after contact with the surface plate.

The bearing shells are usually fitted after the shafts are fully connected with half-couplings when they assume the working position under the effect of rotating masses.

Small scratches and rough surfaces are eliminated by a special burnisher. The bearing shell surfaces contacting the shaft journal shall be first checked by blueing and then by traces from dry friction between the bearing shell and the shaft journal so as to see whether these surfaces need scraping. To locate points that need scraping, the shaft journal is to be coated with a thin layer of paint made of minium, blue, or ivory black mixed with low-grade olive oil to obtain a thick compound. The paint shall not be applied too generously as in this case it will cover surfaces that do not want scraping.

The painted shaft journal is to be placed onto the surface of the bearing shell and given two or three revolutions. The projecting spots on the bearing shell will be marked with paint. After that the shaft must be raised, the shells rolled out and the painted spots removed with a scraper. The shafts can be lifted by means of wedge jacks or a tool illustrated in Fig. 16.13.

A more thorough finish of the bearing shell surfaces shall be made by traces of dry friction, i.e. without painting the shaft journal. To this end, the journal and the shell are to be wiped with a dry rag, the shaft lowered onto the shell surface and given two or three revolutions more. Rough surfaces will be shown by glittering spots which shall be removed with a scraper.

In order to speed up the fitting procedure, it is good practice to finish all the bearing shells of the motor-generator set simultaneously. After the fitting procedure is completed, the clearances and interferences in the bearings must be checked.

The clearances in the bushes of non-split bearings are to be determined by measuring the shaft journal diameter with a micrometer snap gauge and the bush hole diameter, with an internal micrometer. Feeler gauges may be useful

Table 17.1

Permissible Clearances Between the Shaft Journal and Bush of a Non-Split Bearing

Shaft diameter, mm	Clearances between shaft journal and bush of non-split ring-lubricated bearing, mm			
	free-running fit (Л) for machines running at up to 1000 r/min		loose-running fit (Ш) for machines running at 1000 r/min and higher speeds	
	minimum	maximum	minimum	maximum
80-120	0.08	0.12	0.12	0.17
120-180	0.10	0.15	0.15	0.21
180-260	0.12	0.18	0.18	0.25
260-360	0.14	0.21	0.21	0.29
360-500	0.17	0.24	0.25	0.34

to check clearances at easy-to-get-at places of an assembled bearing. Irrespective of the clearance measurement method used, the shaft journal must be checked for contact with the top of the bush in a non-split bearing or with the upper shell of a split bearing. With the shaft rotated the journal must

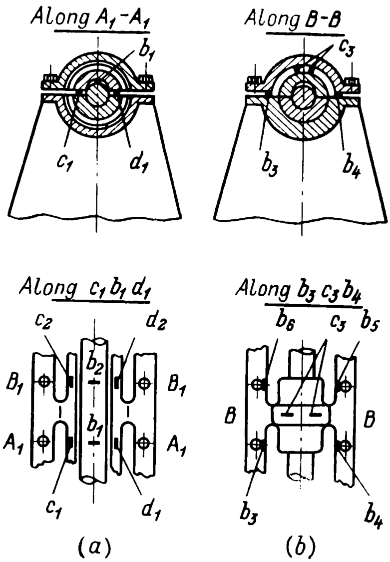


Fig. 17.2. Measurement of bearing clearances

not come in contact with these surfaces. In the process reference shall be made to Manufacturer's Instructions or to data specified in Table 17.1.

Clearances in bearings with split shells are to be determined by an indentation method with the aid of lead plates or 10-20 mm lengths of wire 1 to 1.5 mm in diameter. To determine the clearance between the upper shell and the journal (Fig. 17.2*a*) place pieces of wire on the split joint of the shell at two points (on both ends) and on the shaft, then fit in position the upper shell and the bearing cap and turn in the bolts well home. Then disassemble the bear-

ing and measure the thickness of flattened wires with a micrometer.

Determine clearances a_1 and a_2 at surfaces A_1A_1 and B_1B_1 from the equations

$$a_1 = b_1 - \frac{c_1 + d_1}{2}; \quad a_2 = b_2 - \frac{c_2 + d_2}{2} \tag{17.1}$$

where b_1, b_2, c_1, d_1, and d_2 are thicknesses of respective wires.

The difference between a_1 and a_2 is not to exceed 10 per cent.

Example. The diameters of flattened wires, as measured with a micrometer, are as follows: $b_1 = 0.56$ mm, $c_1 = 0.3$ mm, $d_1 = 0.36$ mm; $b_2 = 0.53$ mm, $c_2 = 0.32$ mm, $d_2 = 0.3$ mm. Determine clearances a_1 and a_2:

$$a_1 = b_1 - \frac{c_1 + d_1}{2} = 0.56 - \frac{0.3 + 0.36}{2} = 0.23 \text{ mm}$$

$$a_2 = b_2 - \frac{c_2 + d_2}{2} = 0.53 - \frac{0.32 + 0.3}{2} = 0.22 \text{ mm}$$

$$a_1 - a_2 = 0.23 - 0.22 = 0.01 \text{ mm}$$

The difference between clearances a_1 and a_2 makes up 5 per cent which meets the requirements.

In checking the clearances between the upper shell and the journal in case of split bearings refer to Table 17.1 and find average values. With force-lubricated bearings the shell bore is to be 0.2 or 0.3 per cent greater than the diameter of the shaft journal.

The amount of interference in the bearing cap shall be checked in addition to the clearance between the upper shell and the shaft journal when the bearing shells are not clamped together with bolts. The interference fit of the bearing cap, which is actually inadmissible, is a negative clearance between the cap and the upper shell (Fig. 17.2*b*).

Clearance a_3 is to be found from the equation

$$a_3 = c_3 - \frac{b_3 + b_4 + b_5 + b_6}{4} \tag{17.2}$$

where c_3, b_3, b_4, b_5, and b_6 are thicknesses of respective wires.

When clearance a_3 between the cap and the upper shell is negative, there will be an interference and not a clearance.

Example. The diameters of flattened wires, as measured with a micrometer, are as follows: $c_3 = 0.32$ mm, $b_3 = 0.3$ mm, $b_4 = 0.36$ mm, $b_5 = 0.34$ mm, $b_6 = 0.36$ mm. Determine the value of a_3:

$$a_3 = c_3 - \frac{b_3 + b_4 + b_5 + b_6}{4} =$$

$$= 0.32 - \frac{0.3 + 0.36 + 0.34 + 0.36}{4} = -0.02 \text{ mm}$$

So, we see from the calculation that there is a negative allowance or interference of 0.02 mm between the bearing cap and upper shell.

If the clearance between the shaft journal and the upper shell is too large, the latter can be brought to the working condition on the site of installation without the renewal

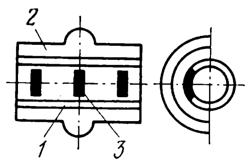


Fig. 17.3. Building up babbit bosses on the upper shell to reduce bearing clearance

1 — babbit liner; *2* — bearing housing; *3* — babbit boss

of the babbit lining. Since the upper shell is not meant to take any load with the exception of thrusts caused by the running shaft, the clearance can be reduced to the normal value by building up babbit bosses of the required height. Such bosses are to be built up on the bearing shell at three points as is shown in Fig. 17.3.

For this purpose make use of a soldering iron and babbit additive of the same composition as the bearing lining. In order to obtain a more reliable adhesion between the built-up babbit and the lining, make small grooves in the shell by a hot soldering iron beforehand. These grooves shall be thoroughly cleaned off with a scraper prior to building up the babbit bosses. In the process, rosin shall be used as a flux. The size of bosses depends on the size of bearings. Usually they are made 10 to 15 mm wide and up to 50 mm long. The newly built-up bosses must be cleaned off. Excess babbit

may be easily removed by means of the shaft journal turned with a rope if their height is not too great. After the desired height of bosses is obtained the clearances shall be checked once again.

Assembling the bearings. The bearing caps are to be mounted against the check pins. In the action, check the holes in the upper shell and in the bearing cap for alignment so as to pass oil to the bearings.

The split joints of the bearings must be also properly fitted; they can be scraped, if necessary. With the bearing halves fitted correctly the split must not pass a feeler gauge 0.05 mm thick. The joints must never be packed with gaskets of any kind. The surfaces of the joints can be coated with bakelite varnish whereupon the bearing fitting procedure may be considered as completed.

The shaft play (or clearances between the shaft necks and the butt ends of the bearing shell) is to be measured with a feeler gauge or a dial gauge. The permissible play for the shaft shall be specified by the Manufacturer. If the Manufacturer's documents do not specify this value, the shaft play is to be determined as follows: from 2 to 4 mm for shaft journals having a diameter of up to 200 mm, and two per cent the journal diameter for those having a diameter over 200 mm. These clearances are necessary to allow for thermal expansion of the shaft.

The electrical machine shafts are packed with circular grooves filled with grease, felt rings, or sealing glands. Wide application have recently found sealing rings made of oil-resistant synthetic rubber. Prior to fitting the sealing rings on the shaft, thoroughly examine them for dirt and defects, and check them for roundness. Sealing rings are widely used at high peripheral speeds (over 5 m/s) and high temperatures.

Such packings are most important for sleeve bearings and antifriction bearings lubricated with mineral oils. In addition to the protection of bearings and bearing oil from dirt, these packings prevent oil leakage from the bearings. The amount of oil to be added in the lubricating system greatly depends on the condition of the shaft packing arrangements.

After the bearings are assembled, connect the oil pipeline. For bearings insulated from the foundation it will be

necessary to check the insulation resistance after the oil pipeline is set in place and the check pins are installed, but before completely closing the bearings. The results of measurements of bearing clearances and insulation resistance must be entered in technical documents for the installation of large electrical machines.

Antifriction bearings. Faulty antifriction bearings revealed during inspections must be replaced with new ones. The bearings may be considered as faulty (in a new machine delivered in an assembled condition) in the event of a distortion of the geometry of balls and rollers as a result of cold hardening (the so-called Brinell effect, see Chapter Ten).

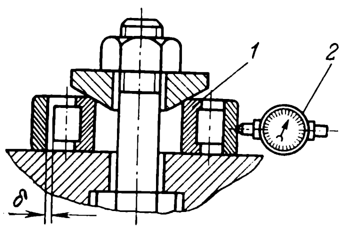


Fig. 17.4. Arrangement for measuring the antifriction-bearing radial clearance

A faulty antifriction bearing in a machine in service can be recognized by the clearance between the balls or rollers and the tracks in the bearing races. This clearance can be measured with a feeler gauge in bearings with short cylindrical rollers or by special arrangements in other antifriction bearings.

Figure 17.4 illustrates an arrangement for measuring the radial clearance δ of an antifriction bearing *1* by the displacement method at a load of 15 kg. The clearance is measured with a dial gauge *2*. The amount of clearance, however, is not the only characteristic determining the degree of wear of an antifriction bearing. The latter will be also considered as faulty in the event of chipped metal, cracks, traces left by rollers on the tracks, dull surfaces of the tracks, nicks at the cage edges or on the butt ends of the rollers, circular grooves on the balls or a distorted geometry of the latter.

A faulty bearing is to be removed and replaced with a new one of the same type. Bearings are to be removed with the aid of various pullers. If the bearing is expected to be used in further operation, it shall be gripped by the inner race so as not to impose the puller pressure on the balls or rollers.

If the puller force is insufficient, the bearing shall be heated. A faulty bearing can be heated by any method, even by open flame of a gas burner. Bearings in serviceable condition must be heated by the induction method.

Figure 17.5 shows an induction heater designed for heating the inner races of roller bearings to be removed from the shaft. The heater coil is made of copper tubes *4* which

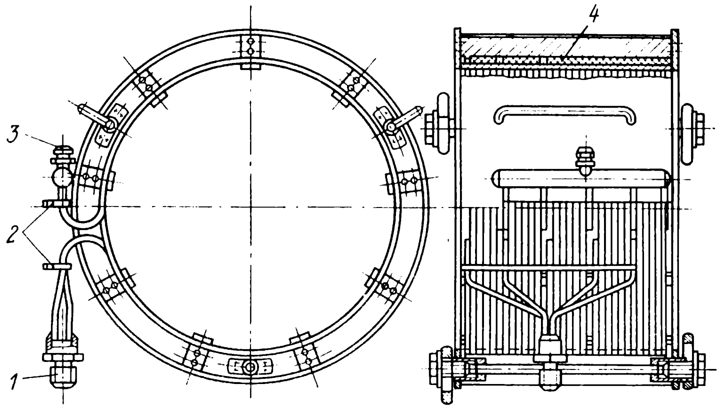


Fig. 17.5. Induction heater for roller bearing races

pass circulating water. Water is delivered to the heater through a pipe union *3* and discharged therefrom through a pipe union *1*. The heater is connected to 40-V ac power supply by means of strips *2* welded to the pipes. It takes 3 minutes to heat the bearing.

The bearings shall be thoroughly washed before mounting and checked for easy rotation. The fitting surfaces on the bearings and on the shaft are to be washed with kerosene and wiped dry with clean waste. Then these surfaces are to be closely examined and all defects, such as nicks, rust, etc. are to be removed.

The diameters of fitting portions are to be checked with indicator and plug gauges at three points spaced uniformly over the circumference so as to make sure that they are true. It shall be borne in mind that if the shaft is not round, the bearings may rapidly wear out in the course of operation.

A number of tools are used for mounting the bearings, the simplest one being shown in Fig. 17.6. This tool is made of a soft-metal pipe *2* with a rim *1*. The pipe diameter shall be somewhat greater than the diameter of bearing *4*. The pipe is closed at the end with a metal plug *3*. Such a tool is most suitable for handling small bearings.

Bearings mounted on the shaft with an appreciable amount of interference shall be preheated in oil to a temperature of

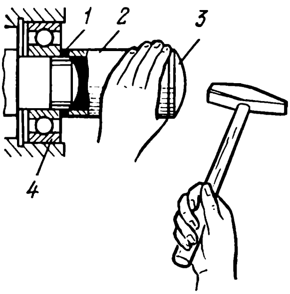


Fig. 17.6. Mounting the ball bearing on the shaft

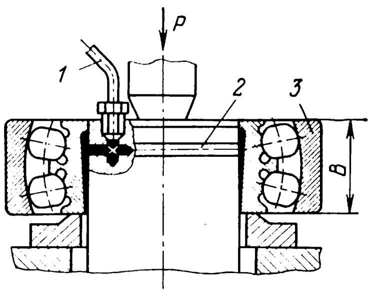


Fig. 17.7. Pulling the bearing off the shaft by hydraulic thrust method

up to 90° C. If the outer bearing race is interference fitted, the bearing housing shall be heated. A great force is needed for mounting and removing bearings having an interference fit.

A three-arm multipurpose puller described in Chapter Fourteen is used for removing the bearings. As an alternative, the so-called hydraulic thrust phenomenon can be utilized. The hydraulic thrust is obtained by a thin layer of oil introduced at a high pressure between the fitting surfaces.

As a result, the bearing race expands, the friction between the fitting surfaces reduces, and the bearings are fitted onto the shaft or removed from the latter much easier.

When the hydraulic thrust method is used, oil forced by a pump via a pipe *1* (Fig. 17.7) is admitted into a distribution slot *2* made in the shaft and forms a film which separates the mating surfaces throughout the entire length with the exception of small portions at the edges preventing

oil leakage. When an axial thrust P is applied to the shaft end, the surfaces are separated under the condition of a wet friction as long as the distribution slot is covered by bearing *3*. As soon as the slot gets opened, the pressure in the pump drops, but the oil film still remains between the fitting surfaces. The advantage of this method is that the fitting surfaces do not wear after the bearings are repeatedly pulled off, and the specified interference is retained.

Hand-operated oil pumps are employed to create a hydraulic thrust. In the event of relatively small bearings use can be made of an injector (Fig. 17.8). The injector consists of a housing *1*, a sleeve *2*, and a grip *3*. A plunger *5* moves within the housing. To prime the injector, set the sleeve in the extreme upper position, pull the plunger till it is stopped by slide block *4*, and fill the housing with oil. Turning the grip forces oil into the distribution slot in the shaft.

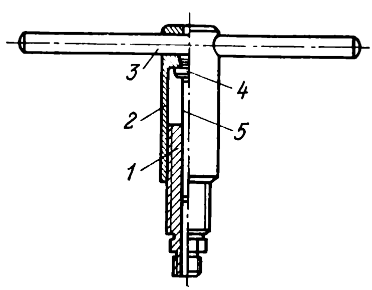


Fig. 17.8. Injector used to create hydraulic thrust

High-viscosity mineral oil (such as industrial oil 20 or 30) shall be used for the purpose. To create a hydraulic thrust, the oil shall be delivered at a pressure of 500-600 kgf/cm². The temperature of oil shall not be lower than 15-20 °C.

CHAPTER EIGHTEEN

Installation of Cooling System for Large Electrical Machines

The cooling systems of *self-cooled* and *fan-cooled* electrical machines are to be mounted by the electricians in charge of the installation of these machines. The mounting procedure consists in the installation and fixation of the fan on the rotor shaft in compliance with reference drawings and Manufacturer's instructions, check-up and cleaning of clogged cooling ducts of self-cooled machines, installation of a protective shroud on the external fan of fan-cooled machines.

The cooling systems of *independently* cooled machines (*open-circuit* and *closed-circuit* cooling systems) shall be mounted in compliance with Manufacturer's instructions by personnel responsible for the installation of the industrial ventilation and plumbing accessories on the site of installation of the electrical machines. This work shall be carried out under the supervision of electricians in charge of the installation of the electrical machines. Electricians dealing with the installation and adjustment of electrical machines also take part in the adjustment and debugging of the cooling systems (for more detail see below). Installation of open-circuit cooling systems primarily consists in the installation of air cleaners and fans. In mounting the closed-circuit cooling system the following operations are to be carried out: hermetic sealing of the machine interior (this is particularly important for hydrogen-cooled machines), installation of surface water coolers for cooling down the hot air, installation of air or gas cleaners, installation of fans. The open-circuit and closed-circuit cooling systems shall be furnished with fire-fighting facilities, automatic control and test equipment, starting and control gear.

Installation of air cleaners. The most frequently used are cell-type and mechanically cleaned panel-mounted air cleaners, cell-type air cleaners being preferable for these

cooling systems. The cell-type filters are made of corrugated metal gauze or contain a filtering medium (fiberglass, metal shavings, etc.). The cells are accommodated in a metal frame of a solid structure which is tightly fitted in the cooling duct at the air intake port of the machine or within a dust-cleaning box. The points of installation of the air cleaner cells are sealed by means of felt or cotton gaskets covered on one side with a varnish or epoxy resin. Before setting the filtering cells in the working position, give them the following treatment: flush in a 10 per cent soda solution at a temperature of 60-70° C, then in hot water at 40-50° C, whereupon place them in an inclined position to drain water, gradually and repeatedly dip the cells in spindle oil No. 2 or No. 3 for one or two minutes and keep them in an inclined position for 24 hours to allow excess oil to drain. The oil consumption per cell is 200-300 g.

Installation of surface water coolers. The surface water coolers used for cooling down the hot air are to be installed in the following sequence: give the air coolers a hydraulic test at a pressure specified by the Manufacturer or, if such data are not available, at a pressure of 0.3 MPa, for 5-10 minutes; eliminate leakage after the pressure test; repeat the pressure test; mount the coolers in the working position and connect them to intake and drain pipes; fit thermometers in the seats of the pipes for controlling the cooling water temperature; seal all the joints of the machine. Air or gas leakage from a force-cooled machine, penetration of dirty air inside the machine, sweating (appearance of dew point) of the water cooler shall be reduced to a minimum. Joints between the stator frame and the end shields as well as all the joints in the air ducts shall be packed with felt or wool gaskets varnished on one side. If the cooling system sweating is persistent, cooling air can be drawn in from the atmosphere provided the outdoor air temperature is lower than that of air in the cooling system (which is usually the case in winter time) so as to reduce the temperature difference between the cooling air and the cooling water. Outdoor air is admitted through an additional viscin air cleaner.

All the air ducts and hot-air boxes must be provided with thermal insulation made, for instance, of asbestos sheets, 5 mm thick, covered with sheet or sheet iron.

CHAPTER NINETEEN

Test, Installation, and Wiring of Current-Carrying Parts

19.1. Designation and Check-up of Winding Leads

The winding leads of electrical machines bear identification markings in compliance with Standard Specifications (see Tables 19.1, 19.2) or, sometimes, with Manufacturer's instructions and certificates. These identification markings shall be referred to in checking the winding leads

Table 19.1

Identification Markings on Winding Leads of DC Machines to Soviet Standard (GOST) 183-66

Winding	Starting lead	Finishing lead
Armature winding	Я1 (A1)	Я2 (A2)
Compensating winding	K1	K2
Commutating winding	Д1 (CP1)	Д2 (CP2)
Series field winding	C1	C2
Shunt field winding	Ш1 (Sh1)	Ш2 (Sh2)
Equalizing winding and expansion wire	У1	У2
Starting winding	П1	П2
Independent excitation winding	H1	H2
Special-purpose winding	01; 03	02; 04

for proper connection in accordance with the internal wiring circuits of the machine.

If a dc machine has more than one winding serving the same purpose, the starting and finishing leads of such windings bear numerical markings in addition to letter designations (1-2, 3-4, 5-6, etc.).

Direct-current machines running as motors in the clockwise direction have all their windings, with the exception

Table 19.2

Identification Markings on Winding Leads of AC Machines to Soviet Standard (GOST)183-66

Winding	Number of leads	Starting lead	Finishing lead
Field (inductor) winding of synchronous machines	2	И1	И2
Stator (armature) winding, open-delta connection:	6		
phase 1		C1	C4
phase 2		C2	C5
phase 3		C3	C6
Stator (armature) winding, star connection:	3 or 4		
phase 1		C1	
phase 2		C2	
phase 3		C3	
neutral		0	
Stator (armature) winding, delta connection:	3		
terminal 1		C1	
terminal 2		C2	
terminal 3		C3	
Rotor winding of three-phase induction motors:			
(a) with three leads brought out to slip rings:	3		
phase 1		P1	
phase 2		P2	
phase 3		P3	
(b) with four leads brought out to slip rings:	4		
phase 1		P1	
phase 2		P2	
phase 3		P3	
neutral		0	

Table 19.3

Identification Markings on Winding Leads of Pole-Changing Motors

Tapped winding		Dual-speed motors	
1st winding	2nd winding	four-pole	eight-pole
1C1	2C1	4C1	8C1
1C2	2C2	4C2	8C2
1C3	2C3	4C3	8C3
1C4	2C4	4C4	8C4
1C5	2C5	4C5	8C5
1C6	2C6	4C6	8C6

of the differential winding, passing current from the starting lead *1* (+) to the finishing lead *2* (—), as is shown in Fig. 22.1.

The tapped winding leads of pole-changing induction motors have an additional numerical designation placed in front of the capital letters to indicate the number of poles at the particular connection of the machine (see Table 19.3).

Most of ac machines have six stator winding leads brought out (three starting and three finishing leads of phase windings). The phase leads are brought out to the terminal board and connected to terminals so that star or delta connection of phase windings can be easily obtained with the aid of jumpers. Fig. 19.1 illustrates the stator winding leads of ac machines.

The stator winding is sometimes permanently connected in star. In such an event only four winding leads are brought out to the terminal board, i.e. three phase leads (*C1*, *C2*, *C3*) and the neutral lead (0). The winding leads interconnected within the machine and not brought out to the terminal board do not bear identification markings.

Identification markings are applied directly on wire leads, binding posts, cable lugs, bus rings, on escutcheon plates at the binding posts or leads. Hanging tags shall not be admitted.

Table 19.4 gives the identification markings of winding leads of single-phase machines.

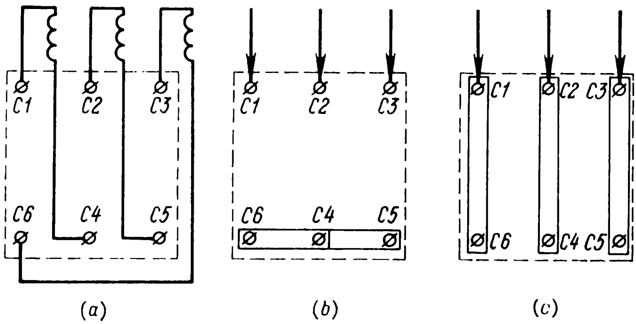


Fig. 19.1. Winding leads of alternating-current machines
(a) connection of leads to binding posts; (b) star connection; (c) delta connection

Table 19.4

Identification Markings on Winding Leads of Single-Phase Machines

Number of leads	Winding	Starting lead	Finishing lead
2	Synchronous machine stator winding	C1	C2
2	Induction motor stator winding		
	(a) running winding	C1	C2
	(b) starting winding	П1	П2
2	Synchronous machine field (inductor) winding	И1	И2

In small-size machines where the space on winding leads is limited, the latter can be identified by coloured braidings in compliance with Soviet Standard (GOST) 183-66.

19.2. Checking the Internal Connections of Windings

The internal connections of windings shall be checked up after the electrical machines are delivered on site (if they arrive in an assembled condition) or after they are assembled

(if dispatched in a disassembled condition). First it is necessary to check the internal connections for compliance with the Manufacturer's instructions and diagrams. All the soldered and bolted joints, as well as other connections and contacts are to be examined. The winding leads shall be checked for correspondence with the internal wiring. All

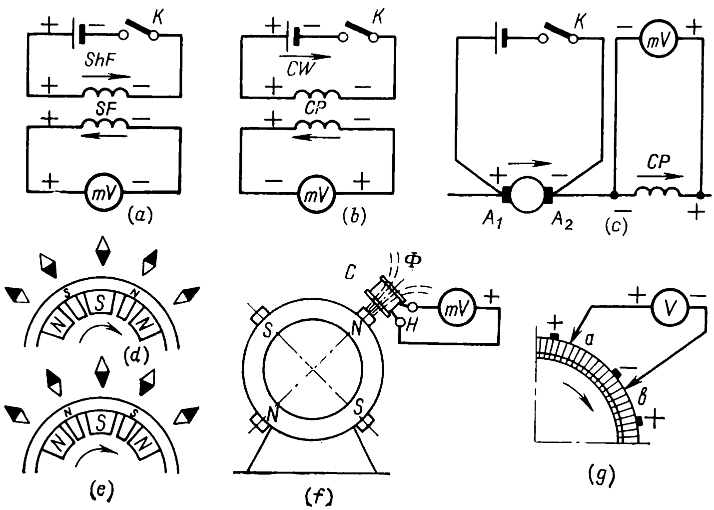


Fig. 19.2. Checking the internal connections of direct-current machine windings

(*a*) identification of polarity of shunt-field (ShF) and series-field (SF) windings by induction method; (*b*) separate checking of compensating (*CW*) and commutating (*CP*) windings for proper interconnection; (c) checking of armature and commutating windings for proper interconnection; (*d*), (*e*) sequence of main and commutating poles; (*f*) checking the machine poles for polarity by means of an auxiliary coil; (*g*) coordination of polarity of brushes, sense of rotation, and polarity of main poles

these operations are to be carried out by electricians in charge of installation and debugging of electrical machines.

Direct-current machines. Figure 19.2 illustrates the diagram for checking the dc machine windings.

The shunt and series (magnetizing) field windings are to be checked *for polarity* by separate trial connections of the shunt winding and then the series winding or by an induction method. In the latter case connect a 1-3 V millivoltmeter *mV* and a storage cell or battery to the field win-

dings (Fig. 19.2*a*). Check the voltmeter for polarity by the identification markings on the storage battery terminals. With the field windings connected cumulatively, a momentary closure of key K will cause a right-hand deflection of the voltmeter pointer while in opening the voltmeter pointer will deflect to the left.

The compensating (CW) *and commutating* (CP) *windings are to be checked separately for interconnection* by using an induction method as is shown in Fig. 19.2*b* proceeding in the same sequence as in checking the polarity of the shunt and series fields. After the polarity of the winding leads is determined, interconnect the windings in series so that the plus lead of one winding is connected to the minus lead of the other winding. In such an event magnetizing forces must act cumulatively.

Checking the interconnection of the armature and commutating windings. This connection is usually checked after a major repair of the machine. A storage cell or battery is to be connected via the key K to the armature terminals $A_1 - A_2$ and a millivoltmeter mV to the commutating pole terminals CP (Fig. 19.2*c*). When the commutating windings are placed in a sequential relation with the coils of a compensating winding, the millivoltmeter is to be connected to their common terminals. By varying the millivoltmeter connection, a right-hand deflection (towards the plus polarity) shall be obtained at the moment the battery is switched on. With the armature and compensating windings connected properly, the magnetizing force of the compensating and commutating windings will oppose that of the armature winding. That is why the armature winding leads are connected to the like-polarity leads of the commutating winding, i.e. the armature plus terminals are connected to the commutating pole plus terminals or the armature minus terminals are connected to the commutating pole minus terminals.

The sequence of the main and commutating poles is usually checked by the deflection of the compass pointer (Fig. 19.2*d* and *e*) which is brought in turn to the binding posts of the respective poles on the outside of the frame. When the polarity of the pointer is unknown (for instance, when a needle suspended from a thread is used for the purpose), the pola-

rity of poles can be indicated arbitrarily. If the pointer response is insufficient, the windings may be supplied with an exciting current in the quantity of 5 or 6 per cent the rated value. The pole sequence must be as follows: in motors, the main pole N (or S) must be followed by the like-polarity commutating pole (as checked in the direction of normal rotation); in generators, the main pole of one polarity must be followed by the commutating pole of the other polarity.

Polarity of main and commutating poles (Fig. 19.2*f*) is determined by means of coil C placed in the pole leakage flux Φ and by a millivoltmeter mV. Coil lead H relative to which the turns are wound in the clockwise direction, as viewed from the side of the machine, is to be connected to the "+" terminal of the millivoltmeter. As soon as the coil approaches the north pole N along its axis, the millivoltmeter pointer will deflect to the right. As the coil is carried away from the north pole, the pointer will deflect to the left. Near the south pole S the pointer will deflect in the opposite direction.

The polarity of brushes, sense of rotation, and polarity of main poles can be checked for correspondence in the following manner. Connect a voltmeter (Fig. 19.2*g*) to two points (*a* and *b*) on the commutator. As soon as an exciting voltage is applied, the voltmeter pointer will give a momentary deflection. For the given marking of terminals, the right-hand deflection of the pointer indicates plus at point *a* and minus at point *b*. The adjacent brushes arranged in the direction opposite to normal rotation have the same polarity.

Another method consists in the following. Apply an exciting current of a predetermined polarity to the field winding. Connect a voltmeter having a scale range of 15 to 30 V to the armature brushes and push the armature (manually, with a lever, or crane) in the direction of specified rotation. The polarity of brushes will be indicated by the deflection of the voltmeter pointer.

Alternating-current machines. When the stator winding leads do not bear identification markings (in the case of large machines, as a rule), they can be identified by using one of the following methods (Fig. 19.3).

Checking by dc voltage with windings connected separately. Connect a dry cell or a storage battery (Fig. 19.3*a*) to one

of the phases (say, phase *I*) and a millivoltmeter in turn to phase *II* and to phase *III*. By varying the millivoltmeter connection obtain the right-hand deflection of its pointer. With this, the starting leads *H* of the phase windings will be against the battery plus terminal and the millivoltmeter minus terminal.

In more important cases or when there is any doubt, this check can be made by *connecting two phases in series* with the

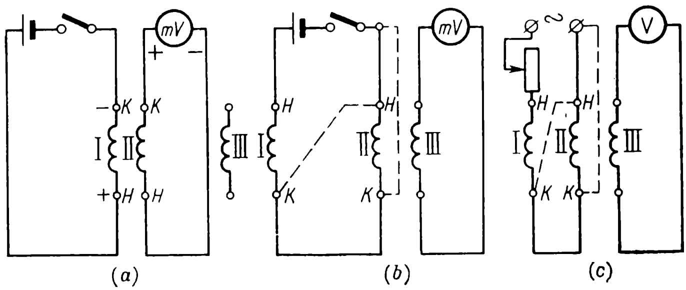


Fig. 19.3. Identification of winding leads of alternating-current machines

(*a*) by direct current with windings switched on separately; (*b*) by direct current with windings series-connected in pairs; (*c*) by alternating current

battery, and the third phase to the millivoltmeter (Fig. 19.3*b*). When the first two phases are connected with like-polarity terminals (as is shown with a solid line in Fig. 19.3*b*), the millivoltmeter pointer will not deflect at the connection of the storage battery. If the phases are interconnected via unlike-polarity terminals (as is shown with broken lines), the millivoltmeter pointer will respond to the connection and disconnection of the storage battery.

Checking the marking of winding leads by ac voltage. Interconnect any two phase leads of the stator winding (Fig. 19.3*c*) and apply a reduced voltage from ac mains (via a rheostat or any other device). Connect an ac voltmeter or an incandescent lamp to the third phase. With the two phases interconnected through like-polarity leads (as is shown with solid lines), the voltmeter or lamp connected to the third phase lead will indicate no voltage. If the phases are interconnected through unlike-polarity leads (as is shown

with broken lines), the voltmeter pointer will deflect or the lamp will come on. Check of the polarity and marking of the leads of the third phase are made in the same way.

All connections of windings at the split joints of machines dispatched in a disassembled condition shall be made by electricians in charge of the machine installation.

Placing the winding coils in the stator slots of ac machines rated 3, 6, and 10 kV, as well as soldering the intercoil connections shall be carried out either by the Manufacturer or by qualified electricians of the User organization.

The winding coils shall be placed in slots in a hot state and in full compliance with the Manufacturer's instructions. It is inadmissible to mount the winding coils in slots without preheating them.

All the intercoil connections shall be made in full compliance with the Manufacturer's instructions. When soldered joints are to be made measures shall be taken to protect the adjacent portions of the windings against damage. The contact surfaces to be soldered or bolted together shall be thoroughly cleaned off and run over with tin. In soldering or tinning use shall be made of rosin and never acid, as the latter is harmful for insulation. The joints to be soldered shall be covered on all sides with asbestos sheets to prevent overheating and damage to the adjacent turns of winding.

Sharp bends of turns shall be avoided in soldering intercoil connections as this may injure their insulation.

Before placing compound windings into slots, the winding coils of these windings shall be heated with a low-voltage current from low-voltage transformers or dc generators. In the heating, the insulating varnish of the coils softens and becomes elastic, which prevents cracks as the coils are driven in slots. The temperature of heating shall be checked by a thermometer at two or three points on the coil. It is also checked while the windings are placed in slots. The heating temperature for windings is specified by the Manufacturer. After all the internal connections of windings are properly made, it is necessary to check all points where conductors pass through the structural elements of the machine, to make sure that the leads are reliably connected to the binding posts, the insulators on the terminals are in good condition and the end portions of windings are fixed in position.

19.3. Checking the Commutator Surface

Before mounting the brush holders, brush rockers, and brushes, while assembling the electrical machines, do not fail to thoroughly examine the commutator surface for burnishing, dents, scratches, projecting and deep commutator bars, high or inadmissibly deep mica.

In the event of high mica or when the mica strips are flush with the commutator bars due to wear of the latter or some other factors, the commutator shall be slotted. For the procedure refer to Fig. 19.4. High mica is to be undercut with a special cutting tool, a simple cutter with saw blades, or a special saw with non-set teeth (Fig. 19.4*c*). The slot depth is to be 1 or 2 mm. The commutator bars shall be bevelled at an angle of 45° over a length of about 0.5 mm. Undercutting shall be carried out at a voltage between commutator bars up to 13 V for mica strips, 0.8 mm thick, and up to 16 V for those 1.2 mm thick. The commutator shall be slotted while its bars are loose as the undercutting procedure is hard to be made after the commutator bars are braced together.

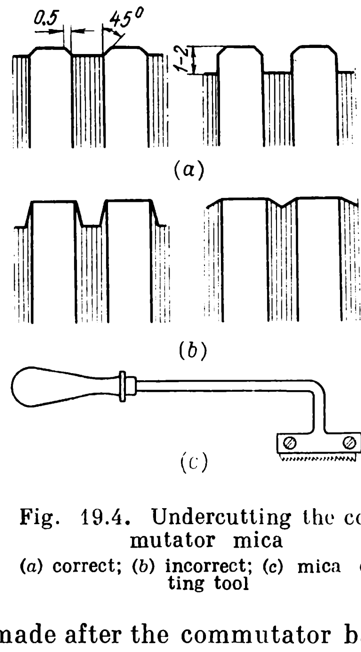


Fig. 19.4. Undercutting the commutator mica

(*a*) correct; (*b*) incorrect; (*c*) mica cutting tool

The commutator surface is to be cleaned of carbon dust with soft non-fluffy rags. Fatty spots shall be removed with rags moistened in alcohol.

The surface of a run-in commutator shall be bright and have a reddish colour (the colour of cuprous oxide), similar for all the bars. Projecting bars wear out and acquire a lighter colouring while deep bars go black.

If rough surfaces exceeding 0.5 mm are detected, the com-

mutator must be turned down. This procedure is to be preceded by mica undercutting and clamping together the commutator bars. The commutator is to be turned down in a a lathe or a special tool fitted with a lathe chuck (Fig. 19.5). Place the tool near the commutator mounted in its own bearings, then thoroughly level it off and secure in position. Fix a cutter in the chuck with its cutting edge somewhat below the centre line of a commutator rotating clockwise or above the centre line if it rotates counter-clockwise

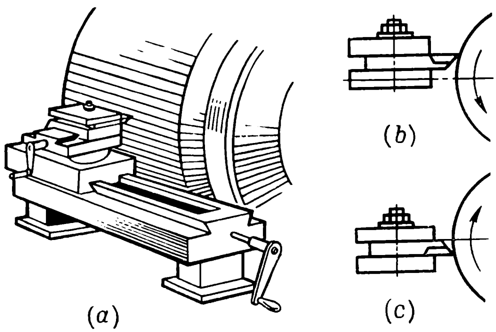


Fig. 19.5. Commutator turning-down tool fitted with a lathe chuck
(*a*) general view; (*b*) setting the cutter tool in the chuck for commutator rotating counter-clockwise; (*c*) setting the cutter in the chuck for commutator rotating clockwise

(Fig. 19.5*b* and *c*). When being turned down, the commutator mounted on the armature shaft rotates in its own bearings. The cutting speed in turning down the commutator shall be 1-1.5 m/s, the cutter feed per revolution is not to exceed 0.05-0.1 mm. If the rough surfaces are within 0.2 to 0.5 mm, the commutator shall be ground, and if roughness is below 0.2 mm it shall be burnished. The grinding and burnishing procedure is described above.

According to data furnished by the Manufacturer, the runout of commutators up to 250 mm in diameter shall not exceed 0.02 mm, that of commutators 300 to 600 mm in diameter, shall be between 0.03 and 0.04 mm, and for commutators having a diameter of 700 mm and larger still the runout shall not be over 0.06 mm. In the absence of Manu-

facturer's data the runout shall comply with the values specified in Table 19.5.

Commutator runout is to be measured by means of a dial gauge at a peripheral speed of the commutator (turned manually or by a crane) not to exceed 1 m/s. The slotted surface of the commutator makes the standard measuring stem of the dial gauge inconvenient for measurements, therefore a flat tip shall be fitted on its end.

Table 19.5

Winding Leads of Single-Phase Machines

Commutator diameter, mm	Speed, r/min	Runout, mm		Permissible difference in runout of cold and hot commutator, mm
		when cold	when hot	
Up to 250	Up to 3000	0.02	0.04	0.02
250-350	750-2000	0.02	0.04	0.02
350-600	600-1250	0.03	0.05	0.03
600-900	500-850	0.03	0.06	0.04
900-1500	450-700	0.04	0.07	0.04
Over 1500	Up to 400	0.04	0.07	0.05

The specified values of runout include bearing clearances, eccentricity of end shields, distortion of the shaft geometry. The runout of the commutator proper is not to exceed half the indicated values.

19.4. Setting and Adjustment of Brush Rigging

The brush rocker of dc machines is to be set against the factory notch indicating the correct neutral. The brushes shall be concentrically spaced around the commutator circumference by appropriately setting and adjusting the brush holders on the brush spindles or arms. To this end the brush holders are to be checked for correct setting with a straightedge placed in parallel with the commutator axis (Fig.19.6*a*, *b*, and *c*). In order to extend the range of commutation, the brushes of every arm shall be shifted relative to one another over the commutator circumference and along its axis

(Fig. 19.6*a*, *b* and *c*). The brushes shall be mounted over the circumference so that the trailing edges of the brushes on adjacent arms are equally spaced apart, otherwise they will short out the offset winding turns and sparking at the brushes may result. Overlap *a* (Fig. 19.6*b* and *c*) between the

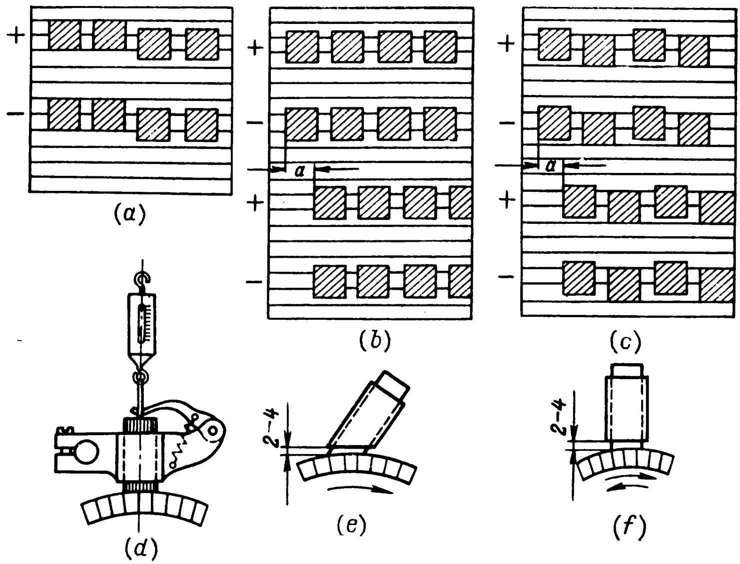


Fig. 19.6. Setting and adjustment of brush rigging
(*a*) stepped setting of brushes; (*b*) staggered setting of brushes; (*c*) stepped-and-staggered setting of brushes; (*d*) checking the brush pressure with spring balance; (*e*) mounting the brush holders in nonreversible machines; (*f*) mounting the brush holders in reversible machines

adjacent pairs of arms may be from 3 to 5 mm. A smaller shift between the brushes shall be set in multiple machines.

For setting the brushes correctly, place a piece of paper divided into equal sections (according to the number of brush arms) on the commutator circumference; set the adjacent rows of brushes at equal distances accurate to $\pm$ 1 mm to ensure a normal operation of the machine. The trailing edges of the brushes shall be spaced apart around the com-

mutator circumference accurate to about 1.5 per cent for machines with power output below 200 kW and not over 0.5 per cent for larger machines.

In non-reversible machines the brush box shall be set in an inclined position at an angle of 15 to 30° to the vertical plane with the pointed end of the brush opposing the armature rotation (Fig. 19.6*e*). In reversible machines the brushes must be set vertically (Fig. 19.6*f*). A clearance of 0.2 or 0.3 mm shall be normally provided between the brush and its box. The clearance between the brush boxes and the commutator shall be within 2 to 4 mm.

Table 19.6

Specifications of Electrical Machine Brushes

Brushes	Grade	Current density, A/cm²	Peripheral speed, m/s	Specific pressure, g/cm²	Where used
Carbon-graphite	T2 T6	6	10	200-250	Generators and motors with medium conditions of commutation
Graphite	Г1 Г3 611M	7 10-11 10-12	12 25 40	200-250 200-250 200-250	Generators and motors with light conditions of commutation
Graphitized	ЭГ2а ЭГ4 ЭГ8 ЭГ14 ЭГ71 ЭГ74	10 12 10 10-11 10-12 10-15	45 40 40 40 40 50	200-250 150-200 200-400 200-400 200-250 175-250	Generators and motors with medium and heavy conditions of commutation as well as slip-ring machines
Copper-graphite	M1 M3 M6 M20 MГ MГ2 MГ4 MГ64 MГC5	15 12 15 12 20 20 15 20-25 15	25 20 25 20 20 20 20 25 35	150-200 150-200 150-200 150-200 180-230 180-230 200-250 150-200 200-250	Low-voltage generators and slip-ring machines

The brush rigging shall be mounted and adjusted so that it can be free to move smoothly (if designed so) as soon as the locking gear is released. When the brush rocker or separate arms with brush holders are fixed in position, provision shall be made to prevent their spontaneous displacement while the machine is running. The brush-lifting gear of induction motors shall provide for shorting out the rotor windings while the brushes are not lifted.

The brush pressure is to be measured with a scale balance illustrated in Fig. 19.6*d*. The tension of the brush springs must be adjusted so as to ensure the specified pressure of the brushes on the commutator (Table 19.6).

The brushes must be bedded to the commutator surface or to the slip rings. To this end, fit a piece of sandpaper under the brushes of two or three arms, rough side up beneath the brush, and draw it in the direction of rotation only. In reversible machines the sandpaper strip can be drawn back and forth. In the process see that the edges of the sandpaper strip are bent down so as to prevent a decrease in the effective area of brushes due to filing off their edges.

After the brushes are bedded to the commutator, the latter shall be blown down with compressed air to remove carbon dust and sand.

Bedding the brushes and cleaning the commutator shall be followed by fitting the brushes to the commutator with the machine running at no load and at full speed.

After the entire brush rigging is properly adjusted, it will be necessary to check its insulation resistance with a megger. If the insulation resistance is below the specified value, the insulating parts shall be dried out or replaced with new ones. A final adjustment of the brush rigging is carried out during the early-failure (debugging) period.

CHAPTER TWENTY

Checking the Electrical Machine Insulation for Moisture Content

20.1. Purpose of Drying the Electrical Machines

The insulation of electrical machine windings and other current-carrying parts may contain excess moisture as a result of careless handling or storage which greatly decreases its resistance. The excess moisture must be removed by drying till the insulation resistance reaches the specified value before the machine is connected to power supply.

In the course of drying, moisture is evaporated from the windings due to the so-called thermal diffusion which causes a migration of moisture in the direction of the heat flow, i.e. from the hottest spots towards cooler ones. The factor responsible for this migration of moisture is a moisture gradient existing between different layers of insulation. As a result, moisture is transferred from damper layers of insulation to less moistened ones. Moisture gradient depends on temperature gradient within wet insulation.

The intensity of insulation drying depends on the temperature gradient and is more intensive at a higher temperature gradient.

The desired temperature gradient can be built up by heating the internal portions of windings (for instance, with electric current passed through the winding) so that a difference in the temperature of the internal and external layers of insulation is obtained. The temperature gradient can be also attained by periodically cooling down the external layers of insulation. To this end, the machine shall be periodically blown down with cold air, which is followed by heating the windings. This method is most suitable for drying heavily moistened windings.

The insulation resistance is measured by means of meggers. For measuring the insulation resistance of electrical machines rated at up to 1000 V use shall be made of 500-V

meggers while 1000-V meggers shall be used for machines rated over 1000 V.

The winding-to-winding and winding-to-earth insulation resistance R_{60}^{*} (in megohms) at the working temperature of the machine shall not be lower than the value found from the equation

$$R_{60}=\frac{V_{rated}}{1000+0.01P} \tag{20.1}$$

where V_{rated} = rated voltage across the machine winding (in volts)

P = rated output of the machine (in kV·A for ac machines and in kW for dc machines)

As a rule, however, the insulation resistance is not to be lower than 0.5 megohm.

The working temperature is assumed to be 75°C. If measurements were taken at a temperature other than 75°C, but not lower than 10°C, the data obtained can be referred to 75°C with the aid of Table 20.1.

As a matter of fact, the insulation resistance will be approximately twice as low for every 20°C temperature increase.

After drying the insulation, resistance at a temperature of 75°C shall not be lower than the values given below:

Stators of ac machines:	
at a working voltage exceeding 1000 V	1M per every kilowatt
at a working voltage up to 1000 V . .	0.5 M per every kilowatt
Armatures of dc machines rated up to and including 750 V	1 M per every kilowatt
Rotors of induction motors, generators, and synchronous condensers (including the entire field circuit)	1 M per every kilowatt
Electric motors rated 3000 V and higher:	
stators	1 M per every kilowatt
rotors	0.2 M

The condition of insulation of newly installed ac and dc machines is now evaluated by a recently introduced method which makes it possible to determine whether a machine can

* Insulation resistance measured 60 seconds after the megger is switched on.

Table 20.1

Insulation Resistance of Electrical Machines at Different Temperatures of Windings

Winding temperature, °C	Insulation resistance, M, at rated voltage		
	3 kV	6 kV	10 kV
10	40	80	135
20	27	56	90
30	20	40	60
40	12	24	42
50	10	16	30
60	5	10	20
75	3	6	10

be placed in operation without drying its insulation. To this end, the following characteristics must be known:

(a) absolute value of the insulation resistance of windings (R_{60}) as measured at a temperature not lower than 10°C;

(b) the value of factor $K_{60} = R_{60}:R_{15}$, i.e. the ratio of two values of insulation resistance read off the megger 15 and 60 minutes after it is switched on (at a temperature of 10 to 30°C);

(c) leakage current through the winding insulation as a function of rectified test voltage ($i_{leak} = fV_{test}$). The i_{leak} *vs* V_{test} curve plotted within the specified voltage range must take a linear form without kinks. The nonlinearity factor $K_{nl} = R_{0.5\ V_{rated}}/R_{V_{max}}$ expressing this requirement shall not exceed a definite value. $R_{0.5\ V_{rated}}$ and $R_{V_{max}}$ in this expression are winding insulation resistances measured at 50 per cent the rated voltage and at the maximum voltage, respectively, this voltage being different for different groups of machines.

A rectifier valve can be used as a source of rectified voltage.

The absolute value of leakage current at different steps of the test voltage varied from 0.5 V_{rated} to V_{max} at a temperature of 10 to 30°C is not to exceed those specified in Table 20 2.

Table 20.2

Permissible Leakage Current

Step of test voltage in relation to the rated value	0.5	1	1.5	2	2.5	3
Maximum permissible leakage current, μA	250	500	1000	2000	3000	3500

(d) C_2/C_{50} ratio of capacitances as measured by the "capacitance-frequency" method for machines rated at a power output up to 5000 kW and a speed of not over 1500 r/min, where C_2 and C_{50} are capacitances of ac machines measured at a frequency of 2 and 50 Hz, respectively. This characteristic does not concern generators, synchronous condensers and synchronous motors having a power output higher than 5000 kW nor is it essential for motors running at a speed higher than 1500 r/min.

20.2. Checking the Insulation of AC Machines

To determine whether the electrical machine insulation meets the requirements stating its suitability for connection to power supply without drying, all the ac machines shall be appropriately grouped as follows:

group 1 — all ac machines of up to 5000 kW output rotating at a speed not over 1500 r/min;

group 2 — electric motors of not over 5000 kW output and all motors rotating at a speed exceeding 1500 r/min, as well as synchronous turboalternators of power stations and synchronous condensers.

Group 2 includes two sub-groups, *viz.* machines rated at a voltage up to 15.75 kV and those rated at higher voltages.

Requirements to be met for throwing the 1st group ac machines in operation without drying their insulation. Electrical machines of the 1st group shall meet one of the following combinations of requirements: requirement (a) plus requirement (b); requirement (b) plus requirement (c); requirement (a) plus requirement (c); requirement (a) or (b) plus requirement (d) (see Section 2.1).

1. Requirement (a) plus requirement (b), i.e. adequate values of resistance R_{60} and absorption factor K_{60}.

The absolute value of winding insulation resistance, as measured at a temperature of 10 to 30°C and referred to 75°C, shall meet the requirements of equation (20.1). Absorption factor $K_{60} = R_{60}:R_{15}$ shall be at least 1.2. If these characteristics are adequate, the machine shall be subjected to a a high-voltage test in compliance with Regulations for Installation of Electrical Equipment (ПУЭ), Clauses 1-8-6 and 1-8-15, whereupon it may be connected to power supply. If this requirement is not met, the other combinations of characteristics shall be checked.

2. Requirement (b) plus requirement (c), i.e. adequate values of absorption factor K_{60} and leakage current as a function of test voltage applied $i_{leak} = f(V_{test})$.

It may be allowed that $K_{60} = R_{60}/R_{15} \geqslant 1.1$. The leakage current *vs* test voltage curve shall be of a linear form, i.e. there shall be no kinks and the nonlinearity factor $K_{nl} = R_{0.5\ V_{rated}}/R_{2.5\ V_{rated}}$ shall not exceed 1.2. The leakage current i_{leak} at different steps of the test voltage is not to exceed the values specified in Table 20.2.

The minimum test voltage for machines of the 1st group is 0.5 V_{rated} and the maximum test voltage is 2.5 V_{rated}. In plotting the leakage current *vs* test voltage curve it will be necessary to define the steps of test voltage in accordance with data specified in Table 20.3.

Table 20.3

Steps of Test Voltage for 1st Group Machines

Rated voltage, kV	Steps of test voltage, kV
3	1.5, 3, 4.5, 6, 7.5
6	3, 6, 9, 12, 15
10	5, 10, 15, 20, 25

The voltage of every step shall be maintained for one minute. During this period the leakage current shall be measured in 15 and 60 s (i_{15} and i_{60}), whereupon the voltage is to be raised to the next step. If leakage current rises at a con-

stant applied voltage, the test shall be ceased, the trouble located and eliminated.

3. Requirement (a) plus requirement (c), i.e. adequate winding insulation resistance R_{60} and leakage currents as functions of test voltage applied. The R_{60} value must be in compliance with the equation (20.1) and the nonlinearity factor is not to exceed 1.2.

The leakage current *vs* test voltage curve for the combination of requirements 2 and 3 is to be plotted only in case one of the requirements (a) or (b) is not met.

Leakage currents are not to be measured for motors having only three leads brought out to the terminal board, which makes it impossible to determine these values for each phase, nor shall they be checked for water-cooled generators having water manifolds directly connected to the windings. These machines must be checked for characteristic (d) in addition to (a) or (b).

4. Requirement (a) or (b) plus requirement (d), i.e. adequate values of R_{60} or absorption factor $K_{60} = R_{60}/R_{15}$ and adequate C_2/C_{50} ratio as determined by the "capacitance-frequency" method.

The R_{60} values, as referred to 75°C, must be in compliance with equation (20.1) or Table 20.1. To meet the requirement (b), the absorption factor $K_{60} = R_{60}/R_{15}$ must not exceed 1.2. The machine may be thrown in operation if one of these conditions is fulfilled and the C_2/C_{50} ratio does not exceed 1.5.

Where the R_{60}, R_{60}/R_{15}, and C_2, C_{50} values cannot be determined for each phase, these values shall be measured for all the three phases relative to the motor frame.

Requirements to be met for putting the 2nd group machines in operation without drying. Requirements (a) plus (c) or (b) plus (c) shall be met for the machines rated up to 15.75kV (1st sub-group).

1. Requirement (a) plus requirement (c), i.e. absolute value of winding insulation resistance R_{60} shall comply with equation (20.1) and the leakage-current *vs* test voltage curve shall be free from kinks. Besides, absorption factor $K_{60} = R_{60}/R_{15} \geqslant 1.2$ and nonlinearity factor $K_{nl} \leqslant 1.3$. The leakage current shall not exceed the values specified in Table 20.2.

2. Requirement (b) plus requirement (c), i.e. absorption factor K_{60} shall be at least 1.3, the leakage current *vs* test voltage curve shall be free from kinks, and leakage current shall not exceed the values specified in Table 20.2.

The 2nd sub-group machines rated over 15.75 kV shall meet all the three requirements to be placed in operation without drying. The winding insulation resistance R_{60} of these machines shall not be lower than that obtained from equation (20.1), the absorption factor K_{60} shall be at least 1.3 and the nonlinearity factor K_{60}, not over 1.2.

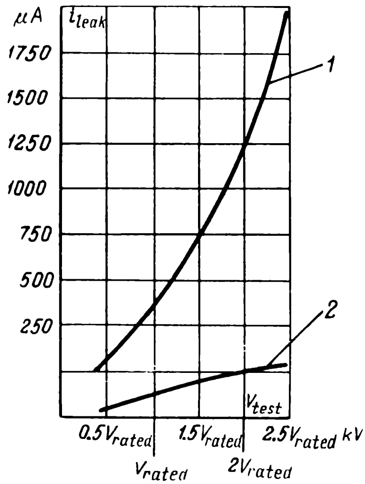


Fig. 20.1. Leakage current (i_{leak}) versus test voltage (V_{test})

1 — for surface moistened winding; 2 — for surface cooled winding after drying-out

For plotting the leakage current *vs* test voltage curve according to requirement (c) the rectified voltage is to be raised from the minimum to the maximum value in steps (five steps according to Table 20.3). The desirable shape of this curve is illustrated in Fig. 20.1.

Table 20.4 specifies minimum and maximum values of the test voltage for the machines of group 2.

The machine shall be cleaned of dust and dirt and blown down with compressed air at a pressure of 2 kgf/cm² before tests. The absolute value of winding insulation resistance R_{15} and R_{60} is to be measured with a 1000-2500-V megger at a temperature not lower than 10°C. At lower temperatures the machine shall be heated. The insulation resistance of stator windings in megohms can be measured by leakage current using a rectifier valve at a voltage of 2 or 2.5 kV, readings being taken at a full voltage of 2 or 2.5 kV

$$R_{15} = \frac{V_{test}}{i_{15}}; \quad R_{60} = \frac{V_{test}}{i_{60}} \tag{20.2}$$

where V_{test} = rectified test voltage, V
i_{15} and i_{60} = leakage currents, μA, measured in 15 and 60 s, respectively

Table 20.4

Test Voltages for Machines of Group 2

Machine output, kW	Rated voltage, kV	Minimum voltage, kV	Maximum voltage, kV
Up to 1000	All voltages	$0.5V_{rated}$	$1.2\ (2V_{rated}+1)$
Over 1000	Up to 3.3	$0.5V_{rated}$	$1.2\ (2V_{rated}+1)$
Over 1000	3.3-6.6	$0.5V_{rated}$	$1.2\ (2.5V_{rated})$
Over 1000	Over 6.6	$0.5V_{rated}$	$1.15\ (2V_{rated}+3)$

R_{15}, R_{60}, i_{15}, and i_{60} shall be measured at each phase for machines having six leads brought out; while these values are checked at one phase the other phases are to be earthed through the frame. If the machine has three leads brought out to the terminal board, these values shall be determined for all the three phases simultaneously relative to earth.

For plotting the $i_{leak} = f\ (V_{test})$ curve, the leakage currents can be measured with the aid of a rectifier valve on condition that the R_{60} value is in compliance with equation (20.1) and the absorption factor K_{60} is at least 1.2 or 1.3 (depending on the machine group). The $i_{leak} = f\ (V_{test})$ characteristic is to be plotted at a test voltage applied in five steps. The leakage currents shall be measured with instruments having an accuracy class not lower than 1.5. The test circuit arrangement incorporating a rectifier valve shall have negligible leakage currents as compared to those of the machine under test.

The nonlinearity factor K_{nl} is to be found from the following equation as a ratio of insulation resistances, as measured by leakage currents at a minimum test voltage $V_{min} = 0.5\ V_{rated}$ and a maximum test voltage V_{max}, the latter being different for different machine groups:

$$\left.\begin{aligned} R_{0.5V_{rated}} &= \frac{0.5V_{rated}}{i_{0.5V_{rated}}}; \quad R_{V_{max}} = \frac{V_{max}}{i_{V_{max}}} \\ K_{nl} &= \frac{R_{0.5V_{rated}}}{R_{V_{max}}} \end{aligned}\right\} \qquad (20.3)$$

where $R_{0.5\,V_{rated}}$ and $R_{V_{max}}$ are insulation resistances of windings determined by leakage currents at a minimum and a maximum voltage.

In the event of kinks in the leakage current *vs* test voltage curve, the machine shall not be thrown in operation without drying irrespective of the nonlinearity factor value. If the $i_{leak} = f\,(V_{test})$ curve has no kinks but the leakage currents exceed the values specified in Table 20.2, the test shall be ceased to locate the cause of trouble.

In case the cause of trouble is not found, the machine shall be heated till the temperature of the winding reaches 75°C (provided $K_{nl} \leqslant 3$). If the value of R_{60} at 75°C is not less than that found from the equation

$$R_{60} = \frac{V_{rated}}{1000 + 0.01P}$$

and $K_{60} = R_{60}/R_{15}$ is at least 1.2 (or 1.3 for the machines of group 1), as measured after the machine is cooled down to 10-30°C, the machine can be connected to power supply without drying.

The windings of electrical machines acknowledged as fit for starting without drying out shall be subjected, prior to start, to a high-voltage test relative to earth at a commercial frequency. The insulation resistance of rotor windings of all the machine groups, as measured at a temperature of 10 to 30°C, shall be at least 0.5 M for generators and synchronous condensers and at least 0.2 M for motors.

20.3. Checking the Insulation of DC Machines

Requirements to direct-current machines for putting them in operation without drying concern only all the commercial rotating machines manufactured in this country rated at up to 1000 V and using Class A or Class B insulation (Table 20.5). These requirements do not concern generator exciters and synchronous condensers incorporated in power systems.

Prior to taking measurements, the machine windings shall be cleaned of dust and dirt by blowing them down with cleaned (oil-free) and dry compressed air at a pressure of not over 2 kgf/cm³ and wiping easy-to-get-at surfaces with dry rags. In the action particular attention shall be given to the insu-

Table 20.5

Insulation Classes of Armature Windings of DC Machines

Electrical machine	Insulation Class
Series П-100 machines; standard-range machines, series П, size 1, 2, 3; type ЗДН generators; type АВ-2 machines	A
Types ГП and ГПМ generators; types МП, ДП, ДПП motors; types ПБК, МПБ, ГПН machines; standard-range machines, series П, size 4, 5, 6	B

lation of winding leads and cleats securing the latter to the frame.

The insulation resistance of windings shall be measured at a temperature not lower than 10°C. If the temperature is below this value, the machine shall be appropriately heated.

In the event of improper conditions of storage before installation, the machine windings shall undergo a check heating procedure before taking measurements at high dc or ac voltages or subjecting them to high-voltage tests.

The dc machines using Class A or Class B insulation for their windings may be thrown in operation without drying provided they meet the following requirements:

1. Absolute values of winding insulation resistance R_{60} for Class A insulation machines rated at up to 500 V, as measured at a temperature not lower than 10°C, shall not be lower than those specified in Table 20.6.

2. Class B insulation machines rated at 500 to 1000 V shall have absolute values of R_{60} not less than those specified in Table 20.1. Besides, their absorption factor $K_{60} = R_{60}/R_{15}$, as measured at a temperature of 10 to 30°C, shall be at least 1.2.

With the results of these measurements being adequate, the machine winding shall be subjected to a high-voltage test with a commercial-frequency ac voltage.

If the absorption factor R_{60}/R_{15} and the absolute value of R_{60} are below the specified value, the windings shall undergo a check heating or they shall be dried out, if necessary.

Table 20.6

Minimum Permissible Values of R_{60} at Different Temperatures

Winding temperature, °C	Insulation resistance R_{60}, M, at rated voltage, V				
	220	460	650	750	900
10	2.70	5.30	8.00	9.30	10.80
20	1.85	3.70	5.45	6.30	7.50
30	1.30	2.60	3.80	4.40	5.20
40	0.85	1.75	2.50	2.90	3.50
50	0.60	1.20	1.75	2.00	2.35
60	0.40	0.80	1.15	1.35	1.60
70	0.30	0.50	0.80	0.90	1.00
75	0.22	0.45	0.65	0.75	0.90

Note. The Table is compiled for machines with Class B insulation but it can also be used for machines with Class A insulation.

The insulation resistance of the machine windings is to be measured by means of a 1000-V megger, with the power-circuit windings (armature winding, compensating, compound and series windings) being connected as in a running machine. In the event of inadequate results the insulation resistance shall be measured for each winding separately.

The insulation resistance can be also checked by leakage currents i_{15} and i_{60} in case a stabilized rectified voltage source of 1000 V is available. The instrument readings are to be taken off as soon as the full test voltage of 1000 V is applied.

The insulation resistances R_{60} and R_{15} as well as the absorption factor K_{60} are to be found from the equation

$$\left.\begin{aligned} R_{60} &= \frac{V_{test}}{i_{60}}\ (\text{M}); \quad R_{15} = \frac{V_{test}}{i_{15}}\ (\text{M}) \\ K_{60} &= \frac{i_{15}}{i_{60}} = \frac{R_{60}}{R_{15}} \end{aligned}\right\} \qquad (20.4)$$

where V_{test} = test voltage, V

i_{15} and i_{60} = leakage currents, μA, measured 15 and 60 s after the full test voltage is applied

CHAPTER TWENTY-ONE

Drying of Electrical Machine Insulation

21.1. General

If the requirements set forth in Chapter 20 are not complied with, the machines shall be dried out before starting, using one of the following methods: external heating, heating by electric current supplied from an independent source, induction heating, heating the machine running as generator with a short-circuit current, creeping-speed drying (for dc motors), and drying out due to windage losses.

In case one of the above methods does not provide for the required drying temperature or the heating is not uniform, a combined drying is employed with the use of not one but two methods for the purpose.

Prior to drying out the machine shall be examined and blown down with compressed air. In the course of drying the windings and iron stacks shall be heated gradually so as to prevent the internal parts of the machine from heating to a critical temperature while the external parts are still cool. Whatever drying method is applied, it shall be borne that the temperature of windings and iron stacks reaches 50°C (as measured by thermometer) not earlier than 10 hours after the beginning of drying and the maximum permissible temperature is attained not earlier than in 20 hours.

At the initial period of drying the insulation resistance of windings must drop due to evaporation of moisture, but as the machine is further heated, it will rise till, at a certain period, it reaches a steady-state value. In order to ensure a gradual increase in the temperature of windings and iron stacks when drying with electric current, the latter shall be increased in steps or turned off for short periods. The current may be increased only after the windings attain a steady-state temperature. The drying procedure may be ceased as soon as the insulation resistance reaches a steady-state value which does not change within 3 or 5 hours.

In the course of drying, measurements are taken of the winding-to-winding and winding to-earth insulation resistance. Each time before taking measurements the insulation residual charges shall be removed. To this end, the machine winding shall be connected to earth for a few minutes.

At the first period of drying the insulation resistance shall be measured every 30 minutes, and after a steady-state temperature is attained it sha l be measured every hour. The results of measurements are to be entered in a service log. These data are also used for plotting insulation resistance and winding temperature *vs* drying time curves. The insulation resistance and temperature of windings shall be measured all the time till the machine has fully cooled down.

21.2. Drying by External Heating

External heating can be afforded by cast-iron resistors or resistance boxes, or special heaters placed under the machine so that local overheating due to direct irradiation of heat or close proximity of the heat source is excluded.

In drying electrical machines with a closed-circuit cooling system these heaters can be accommodated in cooling boxes; the temperature of cooling air shall be controlled in this case by turning off the heaters for a short period of time or by means of a water cooler.

For drying machines having no cooling boxes it will be feasible to use a hot-air blower of 20 to 30 kW power (Fig. 21.1). To reduce heat dissipation the machine shall be covered with boards or a canvas cover pulled on a frame. The boards shall be provided with closed ports which are to be periodically opened to discharge moisture. The power of electric heaters required for heating the air is to be found from the equation

$$P = 0.07 Q_{air} C_p \, (t_2 - t_1), \quad \text{kW} \tag{21.1}$$

where P = power of electric heaters, kW

Q_{air} = amount of air forced by the fan through the chamber formed by boards, m³/min

C_p = air heat capacity equal to 0.273 kcal/kg

t_1 = ambient temperature, °C

t_2 = hot air temperature, °C

The amount of air forced through the chamber per minute (Q_{air}) is assumed to be equal to $1.5Q_{ch}$, where Q_{ch} is the volume of the chamber in m^3.

For approximate calculations, the power of electric heaters may be assumed as 3.5 per cent the machine power for up to 500 kW machines and 1.5 to 3 per cent that for 500 to 1000 kW machines. Air blowers of 20 to 30 kW are practically suitable for all large electrical machines.

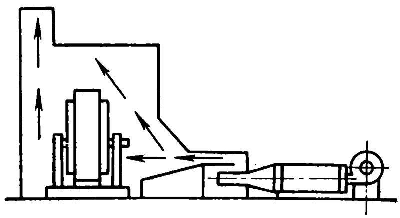


Fig. 21.1. Drying out by external heating with the aid of hot-air blower

In the course of drying the temperature of hot air delivered to the machine must not exceed 90°C and the hottest-spot temperature of windings is not to be over 70°C. The temperature is to be measured by thermometers installed in the air blower pipe union or at the hottest spot of the winding.

Large electrical machines built within the last few years are usually furnished with built-in temperature transmitters (thermocouples).

External heating may be utilized for drying the machines of all kinds, such as synchronous, induction, and direct-current machines. This method is most suitable for heating heavily moistened machines.

Example. For heating an 800-kW synchronous motor a chamber of 12 m^3 (Q_{ch} = 12 m^3) has been constructed. The ambient temperature t_1 = 20°C. The hot-air temperature t_2 shall not exceed 90°C. Determine the air blower power.

The amount of air forced through the chamber per minute $Q_{air} = 1.5Q_{ch}$ = 18 m^3. Hence, the air blower heater will have a power

$$P = 0.07 \times 18 \times 0.273\,(90 - 20) = 24\ \text{kW}$$

Of great interest is an accelerated drying method employed for the first time to dry the dc motors of stands of the rol-

ling mill 700 installed in one of the metal-working plants. This method consists in the following. The condition of insulation of windings is evaluated by the value of absorption factor $K_{60} = R_{60}/R_{15}$ which shall be equal to or higher than 1.2 for good insulation. Since machines having an absorption factor of 1.2 and winding insulation resistance R_{60} complying with equation (20.1) may be thrown in operation without drying (see Chapter 20), it was suggested that the insulation resistance of electrical machines be brought in the course of drying to these values and not to the steady-state condition maintained for 3 to 5 hours.

To check the results of measurements the machines were cooled down whereupon the insulation resistance of windings and the absorption factors were found and the insulation resistance was referred to 75°C. Drying was ceased as soon as an absorption factor exceeding 1.2 was obtained. The drying procedure for different groups of machines took 25 to 35 hours.

The accelerated method of drying saves much time and, surely, will find a wide application. Drying of machines by this method may be ceased only after the insulation resistance has passed the minimum and the absorption factor K_{60} has become equal to or higher than 1.2.

21.3. Drying-out by Heating from External Source

The circuit arrangement for this type of heating, control of drying current and temperature, as well as instruments and devices to be used depend on the type of machine. This section covers methods and circuit arrangements for drying synchronous machines, induction motors, and dc machines.

Synchronous machines are to be dried out by one of the following methods.

1. Connect all the three phases and the rotor (if the latter carries current approaching the rated current through the stator) in series with a dc source as is illustrated in Fig. 21.2*a*. Using a rheostat or varying the supply voltage, maintain the drying current within 50 to 70 per cent the rated current through the rotor. The dc circuit shall not contain any switching element as a breakdown of moist insulation may occur

at an open circuit. The drying current is removed by cutting out the rheostat.

2. Connect the rotor winding to a dc source of the respective voltage. The stator will be heated by the hot rotor (Fig. 21.2*b*). Control the heating temperature by varying the drying current with the aid of the rheostat. Maintain the

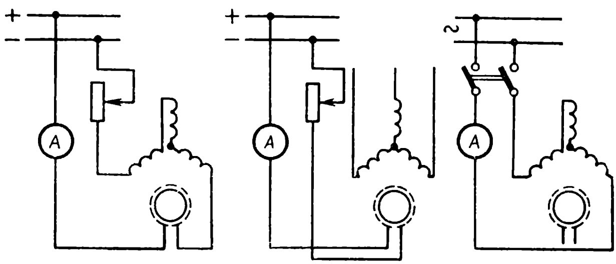


Fig. 21.2. Circuit arrangements for drying out synchronous machines by current from an external source

drying current within 50 to 80 per cent the rated current through the rotor.

3. Set the jumpers on the terminal board so as to obtain an open-delta connection of the stator winding (Fig. 21.2*c*) and connect the machine to a single-phase current source having a voltage 8 to 20 per cent the rated voltage of the stator. The open rotor winding will be dried out by the hot stator.

In drying *induction motors* with the aid of an external source the following methods shall be used.

1. Drying with a three-phase current at a short-circuit running of the machine. Stall the rotor and short it out with a special jumper to prevent burning of the slip rings. The drying current must not exceed 70 per cent the rated value; hence, the supply voltage is not to exceed 70 per cent the short-circuit voltage E_{sc}. In the absence of Manufacturer's data on the short-circuit voltage, determine the latter experimentally. To this end, apply a voltage of 5 to 10 per cent the rated value to the stator with a stalled and shorted-out

rotor and measure the input current through the stator. Find the short-circuit voltage from the equation

$$E_{sc} = V_{st} \frac{I_{rated}}{I_{st}} \tag{21.2}$$

where E_{sc} = short-circuit voltage in volts
V_{st} = voltage applied to the stator
I_{rated} = rated current through the rotor
I_{st} = input current through the stator

When this method of drying is employed, it should be borne in mind that the stalled rotor is acted upon by a magnetic field at a supply frequency of 50 Hz while under normal run-

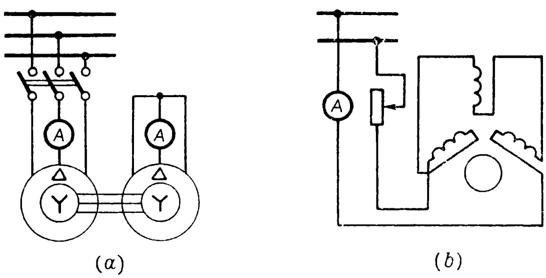


Fig. 21.3. Circuit arrangements for drying out induction machines by current from an external source

ning conditions it is in a magnetic field of a frequency 1-1.5 Hz. The iron stack and other parts of the rotor heat up sooner than the stator windings. That is why the rotor temperature shall be under a close control throughout the entire period of drying. The rotor wire bands must not heat over 100°C.

2. Drying of two similar machines with a three-phase current (Fig. 21.3*a*). Voltage applied to the 1st motor shall make up 15 or 30 per cent the rated value, drying current shall be 50 to 70 per cent the rated motor current.

3. Drying by dc or single-phase current (Fig. 21.3*b*). Connect the windings, having six leads brought out, in series with the source of current. If the machine has only three leads brought out, interchange the phase leads every 1.5 or 2 hours of drying, with the rotor motionless. When a single-

phase current is used, the supply voltage shall not exceed 20 or 30 per cent the rated voltage of the motor and the drying current shall be 50 or 70 per cent the rated value.

When *dc machines* are dried out by this method, the armature, together with the commutating poles and the compound winding, shall be supplied with power from a low-voltage source. The armature shall be slowly rotated in the course of drying. In the process care shall be taken to maintain the brushes at the correct neutral as an unexcited and unloaded motor may run away at a slight displacement of brushes from the neutral plane.

For drying the electrical machines by means of a dc source use can be made of welding motor-generator sets.

In the event of a heavily moistened winding the machine shall be heated starting from a current not over 20 per cent the rated value which shall be further raised to 50 per cent the rated current within 5 or 6 hours.

21.4. Drying by Induction Method

This method is suitable for drying the machines of all kinds. Drying is effected by using one of the two phenomena, *viz.*, core loss in the stator or iron loss in the frame. Heating is afforded by a variable magnetic flux built up due

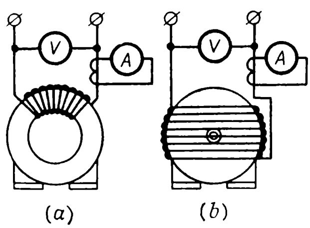


Fig. 21.4. Connection of magnetizing winding for drying by induction method

to a magnetizing winding which is applied to the stator and supplied with a single-phase current. In the former case the winding is applied as is shown in Fig. 21.4*a*. With such an arrangement a negligible magnetic flux is branched off to the frame due to a considerable difference in the permeance

of the stator stack and frame. In the latter case (drying due to iron loss in the stator frame) the magnetizing winding is to be applied as is shown in Fig. 21.4*b*.

Drying due to core loss. This method can be used for all machines where the shaft can be insulated. Where the air gap is large the machines can be dried out both with the rotor removed and held in place. In the latter case the rotor shall be insulated from the bed plate so as to avoid a short circuit through the shaft and the bearing, the result of which may be heavy currents through this circuit. The rotor shall be insulated by sheets of pressboard placed under one of the shaft journals. The condition of this insulation shall be checked in the course of drying by measuring the voltage applied between the shaft and the bearing. The insulation in good condition can be recognized by this voltage being approximately equal to that at the ends of the shaft. During the drying procedure the rotor shall be periodically turned.

Drying of induction machines involves the removal of the rotor as the air gap in these machines is too small to accommodate the magnetizing winding.

In designing the magnetizing winding the following calculations must be made.

1. Determine the number of turns from the equation

$$w = \frac{45V}{0.0001B} \qquad (21.3)$$

where V = voltage applied for drying, V
B = flux density, Gs
B = 6000 to 8000 Gs

Q is core sectional area, cm^2:

$$Q = Kl_c h_c = K\,(l - nb)\,h_c \qquad (21.4)$$

where K = space factor ($K = 0.95$ for varnished stampings and $K = 0.9$ for paper-insulated core)
l_c = core length less cooling ducts, cm
l = total core length, cm
h_c = core height less teeth, cm
n = number of cooling ducts
b = cooling duct width, cm

2. Calculate the required magnetizing force using the equation

$$aw = \pi D_{av} aw_0 \qquad (21.5)$$

where D_{av} = average core diameter, cm
aw_0 = specific magnetizing force per 1 cm of the core length which depends on the grade of core material (see Table 21.1)

3. Find the magnetizing winding current, A:

$$I = \frac{aw}{w} \qquad (21.6)$$

The magnetizing winding is to be insulated from the core with asbestos sheets. The load on the conductor is taken to be 50-70 per cent of normal. The magnetizing winding is to be provided with taps for controlling the heating temperature by varying the number of turns inserted.

Example. The 380-V ac mains is used as a power source for drying out the machines by core loss method. The core dimensions are as follows: l = 100 cm; h_c = 20 cm; n = 10; b = 1 cm; K = 0.95; D_{av} = 100 cm; B = 8000 Gs.

To select a conductor for a magnetizing winding, first calculate the sectional area of the core

$$Q = K(l - nb)\, h_c = 0.95\,(100 - 10 \times 1)\, 20 = 1710 \text{ cm}^2$$

Determine the number of turns for the magnetizing winding:

$$w = \frac{45V}{Q \times 0.0001B} = \frac{45 \times 380}{1710 \times 0.0001 \times 8000} = 12.5 \text{ turns}$$

Take a magnetizing winding of 15 turns.

Calculate the magnetizing force taking from Table 21.1 $aw_0 = 2$:

$$aw = \pi D_{av} aw_0 = 3.14 \times 100 \times 2 = 628\text{A}$$

Now find the field current:

$$I = \frac{aw}{w} = \frac{628}{15} = 41.9 \text{ A}$$

So an aluminium-core conductor of 16 mm² cross section will be suitable at a load on the conductor making up 60 per cent the rated value.

Drying-out due to iron loss in stator frame. Apply the magnetizing winding directly on the stator frame (Fig. 21.4*b*). Welding transformers, which allow current regulation, are most suitable for use as power sources.

Table 21.1

Specific Magnetizing Force

Flux density, Gs	Magnetizing force aw_0	
	for alloy steel	for dynamo steel
5000	0.66-0.85	1.5
6000	1-1.2	2.2
7000	1.3-1.45	2.75
8000	1.7-2	3.7
10,000	2.15-2.8	4.3-5.6

Calculate the magnetizing winding characteristics in the following way.

1. Find power P_m(kW) required for drying from the equation

$$P_m = KF\,(t_{frame} - t_{ambient}) \tag{21.7}$$

where F = surface area of the frame, m^2

K = heat transfer coefficient: $K = 12 \cdot 10^{-3}$ kW/($m^2 \cdot$deg) for a non-warmed machine and $K = 5 \cdot 10^{-3}$ kW/($m^2 \cdot$deg) for a warmed machine

t_{frame} and $t_{ambient}$ = heating temperature of the machine frame and the ambient temperature, respectively; usually $t_{frame} = 90$°C

2. Calculate the specific power loss (kW/m^2) from the equation

$$\Delta p = \frac{P_m}{F_0} \tag{21.8}$$

where F_0 is the surface area of the machine covered by magnetizing winding, m^2.

3. Determine the number of turns for the magnetizing winding

$$w = \frac{VA}{L} \tag{21.9}$$

where V = applied voltage, V
L = turn length, m
A = variable depending on Δp (Table 21.2).

4. Determine the magnetizing winding current (A) from the equation

$$I=\frac{P_m}{V\cos\varphi} \tag{21.10}$$

where $\cos\varphi$ is assumed to be approximately 0.5-0.7. The sectional area of the conductor shall be selected according to the current, taking a current density of about 3 A/mm^2.

Table 21.2

Variable A as Function of Δp

Δp	A	Δp	A	Δp	A	Δp	A
0.1	4.21	1	1.85	1.8	1.49	2.8	1.27
0.3	2.76	1.2	1.72	2	1.44	3	1.24
0.5	2.3	1.4	1.63	2.2	1.39	3.25	1.2
0.7	2.06	1.5	1.6	2.4	1.35	3.5	1.18
0.9	1.9	1.6	1.55	2.6	1.31	4	1.12

Example. For the machine taken in the previous example the surface area of the frame $F = 8$ m^2 and the area covered by the magnetizing winding $F_0 = 4.8$ m^2. The ambient temperature $t_{ambient} = 15$°C. The turn length $L = 4$ m. A 65-V welding transformer is used as a power source.

Select a conductor for the magnetizing winding.

Determine the power requirement for drying taking coefficient $K = 12 \times 10^{-3}$ kW/(m^2·deg) for a non-warmed machine:

$$P_m = KF\,(t_{frame} - t_{ambient}) = 12 \times 10^{-3} \times 8\,(90-15) = 7.2 \text{ kW}$$

Find the specific power loss Δp

$$\Delta p = \frac{P_m}{F_0} = \frac{7.2}{4.8} = 1.5$$

From Table 21.2 we find that variable A for $\Delta p = 1.5$ is 1.6. Determine the number of turns for the magnetizing winding:

$$w = \frac{VA}{L} = \frac{65 \times 1.6}{4} = 26 \text{ turns}$$

Determine the magnetizing winding current

$$I = \frac{P_m}{V \cos \varphi} = \frac{7200}{65 \times 0.7} = 158 \text{ A}$$

Hence, an aluminium-core conductor having a cross-sectional area of 50 mm^2 will be suitable for this magnetizing winding.

21.5. Drying-out by Short-Circuit Currents with the Machine Running as Generator

This method can be used for drying synchronous and direct-current machines provided a drive motor for rotating these machines is available.

Synchronous machines. Short out all the three phases through ammeters (Fig. 21.5*a*) and wedge the power switch.

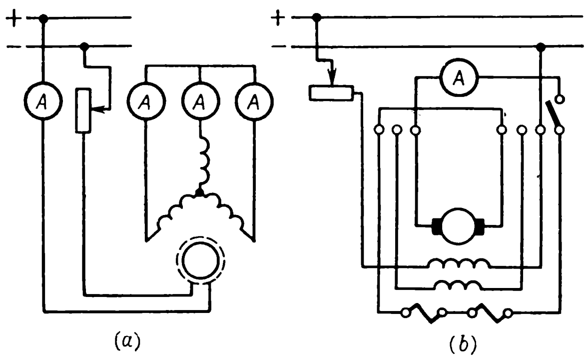


Fig. 21.5. Circuit arrangements for drying out synchronous and direct current machines running as generators

Run the generator at a normal and a reduced speed. Control the machine temperature by varying the field current. The drying current is not to exceed 80 per cent the rated value (0.5 to 0.8) I_{rated}.

Direct-current machines (shunt-wound and compound-wound). Short out the armature and the commutating poles, disconnect the series field winding. Under these conditions the field voltage drops to zero (Fig. 21.5*b*).

Before starting the machine shift the brushes through one or two commutator bars in the direction of rotation. After the machine is started, shift the brushes in the opposite

direction till the desired current is obtained. If it is necessary, connect the shunt field winding to an independent power source via a high-value resistor. If the short-circuit current of the unexcited machine exceeds the permissible drying current, insert a low-value series resistor in the armature circuit. The drying current shall make up 50 to 70 per cent the rated value.

21.6. Drying-out of DC Motors at Creeping Speed

The creeping-speed drying method is used for multipole motors with lap armature winding. This method consists in varying the direction of flux on a part of the poles (usually about 30 per cent) which creates a drag torque for the changed-over poles. As a result, the motor starts running at a very slow speed. The drying current, which must not exceed 50 or 60 per cent the rated value, is adjusted by the magnitude of voltage applied. In the course of drying the field circuit shall be checked for open circuit, which is inadmissible as the motor can run away under such conditions. This method is likewise suitable for drying the generators of motor-generator sets, which considerably cuts down the pre-start period.

Motors having a wave armature winding cannot be dried out by this method as the bars of every parallel circuit of this armature winding are placed under all the poles so that an equal resultant emf is induced in every circuit.

21.7. Drying Due to Windage Losses

This method can be used only for drying high-speed generators, the procedure depending on the mechanical design of the cooling system employed. Where an open-circuit system is used, the drying conditions are obtained by arranging a closed-circuit system. To this end, the air inlets and outlets are shut off and the air is passed from the hot-air box to the cold-air box. With a closed-circuit system the supply of water to the surface cooler is either decreased or stopped with the result that the machine is dried out due to heat dissipated by the windings.

Drying is to be carried out by running the machine at rated speed with the field circuit open, for which purpose it is necessary to remove brushes from one of the slip rings.

To ensure safety, the stator winding shall be shorted out. The drying air temperature is to be controlled in the same way as in the case of drying by short-circuit current. The ports on the generator end shields shall be periodically opened to release evaporating moisture.

This method is rather expensive, therefore it is good practice to use it jointly with other methods, such as drying by using an external power source, etc.

21.8. Checking the Drying Temperature and Other Characteristics

The temperature of windings and iron shall be periodically checked up in the course of drying. For this purpose use can be made of mercury-bulb thermometers, temperature indicators embedded in the machine, built-in temperature indicators; as an alternative, the temperature can be determined by resistance.

Mercury-bulb thermometers shall be mounted at the hottest spots of the windings or on the surfaces of the stator and rotor cores in a position providing for a reliable permanent contact.

Embedded temperature indicators are resistance thermometers or thermocouples embedded in the machine during manufacture at inaccessible points. Built-in temperature indicators (mainly thermocouples) are installed in the machine for the drying period only and shall be removed after the procedure is over.

Determination of temperature by resistance is based on the variation of winding resistance with temperature.

Copper temperature t_2 in a hot winding is to be found from the equation

$$t_2 = \frac{r_2 - r_1}{r_1}(235 + t_1) + t_1 \qquad (21.11)$$

where r_1 and r_2 = resistance of cold and hot windings, respectively

t_1 = temperature of cold winding

235 =constant for copper. For machines wound with aluminium-core conductors this constant will be 245

Table 21.3 specifies maximum permissible hottest-spot drying temperature for windings.

Table 21.3

Permissible Temperature of Machine Parts at Drying

Point of measurement	Method of measurement	Maximum temperature, °C
Winding	By thermometer	70
	By resistance	90
	By temperature detector or thermocouple	80
Outlet air (for machines using open-circuit or closed-circuit cooling systems)	By thermometer	65

While the drying process goes on, put down the temperatures read off all the thermometers and temperature indicators, as well as the insulation resistances R_{15} and R_{60}. From the data obtained plot the winding temperature variation *vs* time and winding insulation resistance *vs* time curves ($T = f(t)$, $R_{60} = f(t)$ and $R_{60}/R_{15} = f(t)$).

In addition to these data enter in the drying log the nameplate data of the machine, the installation site, method of drying, electrical drying characteristics (short-circuit and field currents, magnetizing winding current, etc.), data on associated equipment (welding transformers, hot-air blowers, exciting sets, and other power and heat sources), number and location of thermometers and temperature indicators, methods used for warming up the machine, date of drying, and names of executives in charge.

CHAPTER TWENTY-TWO

Checks, Tests, Trial Start, and Debugging Operations

This Chapter concerns operations to be carried out in checking, testing, and debugging of electrical machines intelligible to qualified electricians trained in the job. The scope of pre-start checks, tests, and adjustments shall be in full compliance with acting standards and regulations, technical conditions of major equipment specified by Manufacturer and design data.

The schedule of pre-start and starting tests and debugging operations shall include measures providing for trouble-free starting of machines and checking of all their electrical characteristics.

Electricians in charge of the machine installation shall carry out the following operations (depending on the machine size, application, and technical condition): external inspection, checking the machine mechanical parts, setting the brushes of commutator machines, identifying the winding leads in accordance with internal connections, checking the machine leads for proper connection to power supply, checking the machine frame for reliable earthing, insulation resistance measurement for small-size (up to 100 kW) ac machines rated up to 380 V and dc machines rated up to 220 V. In addition, they are to take part in measurements of dc insulation resistance of windings, high-voltage tests of windings, in checking and handing over to the User the cooling and lubricating systems with associated control gear. They check the machines for mechanical and electrical characteristics during trial no-load and on-load starting, including the vibration checks, and, together with debugging personnel, take measures to locate the cause of vibration and to eliminate it.

22.1. Checking the Machines and Making Them Ready for Starting

Prior to starting a machine, do the following (the scope of work depends on the type and size of the machine): clean the machine room and the foundation pits of rubbish, dust and dirt; stow away tools and accessories, remove the false-work and other unnecessary items, thoroughly examine the machine for foreign objects using a portable lamp for the purpose; blow the machine down with dry compressed air at a pressure not over 0.2 MPa; make sure that the ventilation system of the machine room is in good condition.

During the **external examination** of medium-size and large electrical machines do the following:

check the machine nameplate data for compliance with design characteristics and those of the major equipment;

check the machine for missing parts;

check the insulation of windings and winding leads, end windings, wire bands, slot wedges, soldered joints at commutator risers for external damage;

examine the surfaces of the commutator, brush holders, and brushes;

check the slip rings, brushes, slip-ring short-circuiting gear and wire leads for condition.

When inspecting the mechanical elements of medium-size and large dc and ac machines carry out the following checks depending on the type and design features of the machine;

make sure that the coils are tightly fitted on poles;

check ring-lubricated sleeve bearings and roller bearings for normal clearance; see that the oil-control rings are free from dents and burrs, that they are free to move and that there is no misalignment at the joints of split rings; make sure that the fixing screws are not sunk;

check disc-lubricated bearings for loose fitting of the scraper and for clean oil-drain labyrinths;

check bearings for the amount and grade of oil;

check the shaft seals for condition;

check the antifriction bearings for correct assembly and packing with grease, for the grade and amount of grease in compliance with Manufacturer's instructions;

check the foundation and bearing fastenings, the binding posts, wedges, end shields, main and commutating poles. When turning in the fastening bolts with a wrench, apply maximum force permissible for the particular bolts. Bolts painted at the Manufacturing plant along with the machine are not to be checked for tightness;

check the air gap of machines assembled on the site of installation.

For the final check of mechanical parts turn the machine by hand, with a special facility, winch, or a crane. In the action, check the shaft for easy rotation and for end play, as well as for jamming, knocking, or scratching. Check the bearings for normal noise, make sure that oil is supplied normally to the oil-control rings. If the machine shaft was turned prior to a trial start, oil is to be supplied to the bottom of the bearing shells as in turning the shaft could displace it therefrom under the effect of the motionless rotor.

While turning the machine artificially create an end play on the shaft and make sure that this action does not cause any seizure between the fan and the bearing cap, between the brushes of induction motors and the wound-rotor insulating discs, between the armature risers and the brush guides, and that the lubricating rings are not wedged. The end play in the bearings usually makes up from 1 to 4 mm depending on the construction and size of the machine.

The brushes are to be checked for proper fitting to the commutator or slip rings, for correct staggering to improve commutation, for uniform spacing along the commutator circumference, for even pressure and easy movement in the brush holders. The brush holders are to be mounted so as to set the brushes in parallel to the commutator bars with the trailing edges of the brushes being spaced one pole pitch apart.

The winding leads and internal connection circuit shall be identified in compliance with standards of Manufacturer's specifications. In the latter case Manufacturer's markings shall be considered as standard.

In the absence of identification markings on the winding leads, the latter can be identified by the induction method using ac or dc supply. The winding leads of large machines

shall be identified even when they bear Manufacturer's markings. The winding leads of dc and ac machines can be identified by corresponding methods.

The number of poles of a stator winding can be determined by means of a dc galvanometer connected across the leads of one or two phases of the stator winding. Turning the rotor by hand induces an emf in the stator winding due to residual magnetism. This emf causes periodical deflections of the galvanometer pointer, the number of deflections in either direction indicating the number of like poles of the rotor passing the given phase of the stator.

Example. At ten revolutions of the shaft the galvanometer pointer makes 31 deflections in either direction, which indicates that the number of pole pairs of the machine $p = \frac{31}{10} \simeq 3$. At a frequency $f = 50$ Hz the synchronous speed of the machine $n_s = \frac{60f}{p} = \frac{3000}{3} = 1000$ r/min.

A correct connection of winding leads to supply mains will ensure a proper sense of rotation of the machine. With a correct phase sequence and proper colouring of the supply phase leads, the stator winding leads of *alternating-current machines* shall be connected as follows: lead *C1*, to phase 1 painted yellow, lead *C2*, to phase 2 painted green; lead *C3*, to phase 3 painted red. The supply leads can be checked for correct colouring by checking the phase sequence with a phase detector or by connecting a small induction motor whose stator leads are known to be marked correctly. The supply mains is to be checked for correct phasing-out by means of a phase detector connected via a three-phase voltage transformer.

In the absence of standard markings on the stator leads the sense of rotation can be determined by one of methods described in appropriate technical instructions for debugging of electrical machines.

All the windings of *dc machines* running as motors with a clockwise sense of rotation, except for the differentially compounded winding, carry current flowing from the starting (+) lead 1 to the finishing (—) lead 2. Fig. 22.1 illustrates the connection diagram of dc motor windings.

Prior to starting, all the machines shall be checked for **reliable earthing of their frames**. The earthing system shall be wired in compliance with the design, the earthing cir-

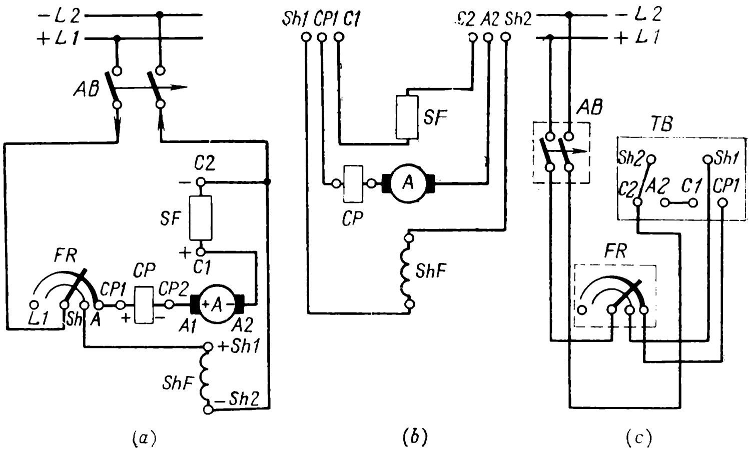


Fig. 22.1. Connection diagrams of direct-current motor windings

(*a*) schematic diagram of compound-wound dc motor for clockwise rotation; (*b*) connection of winding leads of the same motor; (*c*) wiring diagram of the same motor; *ShF* — shunt-field winding; *SF* — series-field winding; *CP* — commutating winding; *A* — armature; *FR* — field rheostat; *AB* — air circuit breaker; *TB* — terminal board

cuit shall be easy to observe, the wires shall bear appropriate colouring, a reliable contact is to be ensured at all the connections, the earthing device shall be checked for leakage resistance.

22.2. Pre-Start Tests of Electrical Machines

Winding-to-earth and winding-to-winding **insulation resistance tests** are most essential in determining whether or not the machine is ready for connection to power supply.

Direct-current machines. Check the insulation resistance of armature winding relative to the frame and wire bands, that of the wire bands relative to the armature; the insulation resistance of commutating, compensating, and field

windings relative to the frame and the winding-to-winding insulation resistance.

Alternating-current machines. A phase winding to be checked is usually disconnected from the circuit and from the earthing system and its insulation is checked relative to the earthed frame, the other phase windings being earthed through the frame. As an alternative, the test can be made with all the windings connected to each other and to power supply. In such tests the windings shall be disconnected only to locate a fault, if detected. When this test method is used, the windings shall be earthed before taking measurements for 3 or 4 minutes to remove residual charge so as to prevent errors in readings.

Interconnected multiphase windings are considered as a single circuit if the starting and finishing leads of each winding are not brought out to special terminals. The multiphase winding is to be tested for insulation resistance relative to the machine frame as a whole.

In measuring the insulation resistance of electrical machines, large machines in particular, put down the megger readings in 15 s and 60 s (R_{15} and R_{60} respectively) since the moment the handle is thrown in rotation.

After the test the windings are placed at a high potential which shall be removed by connecting the earth conductor with one end to the machine frame and with the other, to the winding lead and keeping it in such a condition for 1 or 2 minutes.

The permissible values of insulation resistance for ac machines rated up to 380 V and those for dc machines rated up to 220 V as well as insulation test standards must be in full compliance with acting instructions and regulations. As for machines having a power output in excess of 150 kW and high-voltage machines, reference must be made to Manufacturer's recommendations. According to Standards and experimental data, however, the insulation resistance of electrical machines of all types shall not be lower than 1 M per every kilovolt of the machine rated voltage and is never to be lower than 0.5 M as referred to the working temperature of the machine. The winding -to-earth and winding-to-winding insulation resistance of the electrical machine at *working temperature* (in megohms) must not be lower than

the values obtained from the equation given in Section 20.1 *viz.*,

$$R_{60} = \frac{V_{rated}}{1000 + 0.01P}$$

When the insulation resistance is measured at a temperature lower than the working temperature, the value found from this equation shall be doubled per every 20°C of difference between these temperatures. In all cases, however, the insulation resistance shall be measured at a temperature not lower than 10°C. The insulation resistance-to-temperature relations are given in Tables 20.1 and 20.6.

If the insulation resistance has dropped below the specified values, it is recommended to do the following: blow the machine down with dry compressed air at a pressure of up to 0.2 MPa, clean the winding leads, the commutator butt end, and the insulating parts of the brush holders with clean rags; if cleaning is of no avail, dry out the external surfaces of the windings and their leads with the aid of an air blower.

Measurement of dc resistance of windings is to be made to check the internal wiring for open circuits and the soldered joints for reliability, as well as to determine resistances required for calculations.

With large dc machines and high-voltage ac machines, the dc resistances shall be measured for all the windings. In medium-size and small low-voltage ac machines, the resistance of armature and series compensating windings shall be measured only when it is required to check these windings for condition or to determine the circuit arrangement of internal connections.

These measurements are to be made with a Wheatstone or Kelvin bridge circuit, or by a fall-of-potential method. In the latter case the accuracy class of instruments must be at least 0.2 and the millivoltmeter is to be connected across the winding leads before the ammeter.

The difference in dc resistances must not exceed 2 per cent between different phases and 5 per cent between parallel circuits of windings. The results of measurements must not differ by more than 2 per cent from Manufacturer's data. The results of check of soldered joints at the commutator

risers may be considered as adequate if the resistances or voltages across them, at the same current through the armature, do not differ by more than 10 per cent. For better evaluation of the condition, the resistances are usually referred to 15°C.

High-voltage tests of electrical machine windings are to be made in compliance with Standards and Manufacturer's instructions. These tests are meant to determine the electric strength of winding insulation by applying a high

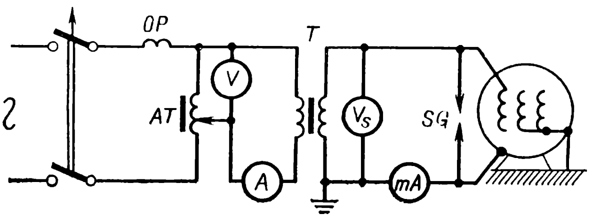


Fig. 22.2. Circuit arrangement for high-voltage test of insulation
T — voltage transformer; V_s — static voltmeter; *AT* — autotransformer; *SG* — spark gap; *OP* — overcurrent protective gear; *V* — voltmeter; *A* — ammeter; *mA* — milliammeter

voltage of commercial frequency and sine waveform as specified by acting Standards. As the winding insulation of new machines is made conservative as far as its electric strength is concerned, it is not to be subjected to high-voltage tests in all cases. These tests shall be made at User's will and usually when the machines are stored in humid atmospheres or assembled on the site of installation, or in some other cases.

The supply source for high-voltage tests is usually a test transformer or a special high-voltage set. Prior to test, the machine insulation resistance (and absorption factor) is to be checked with a megger. The circuit arrangement for testing the machine insulation by applying a high ac voltage is ullustrated in Fig. 22.2.

The source of high voltage is to be connected with its one lead to the lead of the winding under test and with the other lead, to the earthed frame of the machine. The remaining windings are to be earthed through the machine frame. The test procedure is as follows: first apply one third

the specified test voltage to the winding being tested and gradually raise this voltage in steps of not over 5 per cent the full voltage each. The full value of test voltage shall be applied to the winding not earlier than in 10 s. Maintain the full voltage across the winding for 1 minute and then gradually reduce it to one third the test voltage whereupon turn off the supply source. After the tests are over, discharge the windings through the earthed frame and again check their insulation resistance with a megger.

The machine must sustain the high-voltage test for one minute without breakdown. Insulation breakdown can be

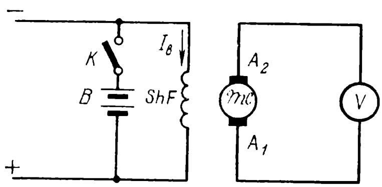


Fig. 22.3. Circuit arrangement for determination of neutral line by induction method with the machine standing still

V — centre-zero moving-coil voltmeter, scale range 3-0-3 V; *B* — 2 to 6 V battery; A_1 — A_2 — machine brushes; *MC* — motor commutator; *ShF* — shunt-field winding; *K* — key

detected by a continuous increase in the leakage current while the test voltage is maintained for one minute.

Setting the brushes to the correct neutral plane can be made by different methods. Fig. 22.3 illustrates the circuit arrangement for determining the electric neutral line by the induction method.

Turning on key *K* feeds a pulse voltage from battery *B* to shunt-field winding *ShF* causing the voltmeter *V* pointer to rush in one direction and then reset to zero; turning off the *ShF* winding deflects the pointer in the opposite direction. The angle of pointer deflection defines the amount of displacement of the brushes from the neutral plane. For setting the brushes to the correct neutral, the brush rocker shall be moved in a position at which the voltmeter pointer makes a minimum deflection. The brush setting on the correct neutral is to be checked at different positions of the ramature as it is turned by hand.

The results of all tests and measurements are to be entered in appropriate reports and other documents stipulated by acting regulations. A motor coupled with a driven mechanism may be started upon the permission of the mechanical equipment installation organization.

Having made sure that the machine is ready for starting, the person in charge shall make an appropriate entry in the service log stating that the circuit may be set up and the machine placed in operation. The overcurrent relay shall be adjusted for some time period to an operating current not exceeding 200 per cent the rated current of the motor; in the event of a step-by-step starting the accelerating relay shall be held with woods in positions making it impossible to cut out the starting resistors. The protective gear is to be checked for opening an oil circuit breaker or an air circuit breaker by manually operating the handle twice.

22.3. Trial Start, No-Load and On-Load Test of Machines

The trial start of motors is to be carried out after measures on safety precautions are taken.

Representatives of the electrical equipment installation and debugging organizations, User's officials, and representatives of the mechanical equipment installation organization (if drive motors are coupled with driven mechanisms) must take part in the trial start tests. It is common practice to give a trial start and to start all the large and medium-size dc motors, synchronous motors, and slip-ring induction motors, as well as motors meant for driving heavy-start mechanisms (such as compressors) while they are not coupled with the driven mechanisms. Squirrel-cage induction motors and small dc and synchronous motors, which are often supplied by the Manufacturer on a common bed plate with the driven mechanisms, are usually coupled with reduction units of the latter by mechanics as soon as the alignment of shafts is completed. In such events the test personnel have to test the motors jointly with the driven mechanisms to avoid disassembly and reassembly of couplings.

Trial start. The first trial start is to be made with an inrush current applied for 1 or 2 s. In the action check the motor rotation, the condition of the rotating parts, the magnitude of starting current, the function of circuit opening devices, overcurrent protection and control gear. The inrush current is to be applied twice or thrice, each time maintaining it for a longer period. With the starting gear and the mechanical elements in good condition, fully cut in the starting resistor to pull in step a synchronous motor or to allow a squirrel-cage induction motor to gain full speed. After the motor has gained speed, switch it off.

In the course of trial start check the mechanical elements of the motor, *viz.*, the oil-control rings of bearings for reliable catching of oil, the machine as a whole for vibration, the brushes for normal commutation, the starting resistors for temperature, the speed control devices for reliable functioning, etc.

With the adequate results of the trial start test, switch on the motor and run it for 20-30 minutes. In the process check the temperature of bearings, windings, iron stacks, the nature and rate of temperature rise and its value. A faulty winding can be recognized by a characteristic smell of burning insulation, which is detected while the winding is not yet hot. When the motors are given a trial start jointly with the driven mechanisms, the latter run idle (the shutters of fans are closed, the pumps are not immersed in water, the conveyers do not carry load, etc.).

After a trial start for 20 or 30 minutes, the motors are to be given a run-in operation for a longer period of 8 to 72 hours (as specified in respective instructions or schedules) in conjunction with the driven mechanisms. During this period the mating surfaces of movable parts of the motor and driven mechanisms become fitted to one another, faulty or unreliable sections of the control circuit detected, the electrical and mechanical pieces of equipment checked for heating. The test schedule is to be specified by executives in charge of the installation of mechanical equipment.

Direct-current generators and exciters are to be accelerated to full speed by means of synchronous or induction motors first started by inrush current and then run in a short-time duty. The generator field winding is switched off and a low

voltage (up to 10 per cent the rated value) is built up across the armature due to residual magnetism. The generator current rises step-by-step till the armature voltage reaches 130 per cent the rated value. In the process, voltage between adjacent commutator bars is not to exceed 24 V. If sparking at the brushes is detected, the exciting voltage shall be reduced or the generator drive motor stopped.

No-load and on-load tests of machines. The insulation resistance of windings shall be periodically checked in compliance with appropriate instructions and regulations at different temperatures of the machine. This temperature is increased while the machine is running at no load and at full load.

Commutation of dc machines is checked by keeping an eye on the commutator while inrush starting current is applied to the machine with the latter running at no load and at maximum voltage and speed.

The degree of sparking is to be checked against the commutation scale stipulated in the appropriate standard. According to the standard, five degrees of sparking (or *commutation classes*) are specified, *viz.*: 1—no sparking (dark commutation); 1 $^1/_4$—slight sparking at some of the brushes; 1 $^1/_2$—slight sparking at most brushes; 2—sparking at all the brushes which may be admitted only at short-time inrush currents and overloads; 3—heavy sparking at all the brushes. The latter may be admitted only at the initial moment of across-the-line starting or reversing of the machine provided the commutator and brushes are maintained in the serviceable condition. The condition of the commutator and brushes at different classes of commutation is as follows: at class 1 and 1 $^1/_4$—no black spots on the commutator, no carbon deposit on brushes; 1 $^1/_2$—black spots and carbon deposit which can be easily removed with a rag moistened with petrol; 2—black spots and carbon deposit which cannot be removed by petrol; 3—black commutator surface that cannot be eliminated by petrol; burning and deterioration of brushes.

During the no-load running, a final check of the dc machine neutral is made (Table 22.1).

A final check of the machine commutation is carried out while the machine is tested under load in different duties. Evaluation of the degree of sparking is of particular impor-

Table 22.1

Determination of Neutral Plane while Machine is Running

Method	Operating duty	Method of determination
Maximum generator voltage	No-load running as generator	At permanent independent excitation move the brush rocker along the commutator. With brushes set on the correct neutral, the generator voltage reaches its maximum
Constant motor speed at reversal	No-load running as motor	Reverse the motor rotation repeatedly. The brushes are at the correct neutral when the motor runs at equal speed in either direction

tance for large machines taking variable loads, such as electric drives of rolling mills, etc. If heavy sparking persists with the commutator, brushes, and brush rocker being in good condition and the brushes set on the correct neutral, the trouble shall be sought in the flux due to commutating poles which lags behind the armature current.

The best of all the known methods to improve commutation under such conditions is a forced automatic boosting of the commutating poles from an external source which is controlled by a signal liable to boost the flux variation.

Miscellaneous instruments are available for measuring the degree of sparking, all of them depending for their operation on different principles. Rather promising are laboratory instruments, such as: MA—degree-of-sparking meter with a magnetic aerial which measures the level of interference due to sparking; ДЩ—degree-of-sparking meter with an additional brush which measures voltage pulses at the trailing edge of a brush relative to the set of brushes, as well as other meters and techniques.

Whenever sparks as long as over 10-15 mm, that may reach the commutator, appear at separate brushes, the machine shall be stopped without delay and the cause of poor commutation located.

The cooling and lubricating systems and the associated devices are to be checked during the no-load and on-load running of the machine in compliance with pertinent instructions supplied by their Manufacturers. These systems are usually checked up and handed over to the User by officials of organizations in charge of their installation. Cooling and lubricating systems of large machines and also the overall ventilation system are installed, as a rule, by the representatives of the mechanical equipment and plumbing fittings installation organization. Electricians and debugging personnel must take part in handing over these systems.

In the process the temperature of the machine parts is given a comprehensive check. The permissible temperature rise for different insulation Classes of machines (A, E, B, F, H) are specified in the corresponding standard and shall be within the range of 60 to 135°C as measured by a resistance thermometer or by temperature indicators placed between the coils of one slot.

If the cooling system constructed in compliance with the design does not ensure adequate cooling of the machine to maintain specified temperature rise, it shall be suitably adjusted, electricians and debugging personnel being invited to take part in the procedure so as to locate the cause of excessive temperature rise in the machine or its parts.

Some typical causes of excessive temperature rise for dc and ac machines as well as remedies thereof are given below.

For instance, the *entire machine runs hot*:

(a) overload. If the load cannot be reduced and there is no sparking at the brushes, improve cooling conditions for the machine by installing an additional fan or fan blades upon agreement with the Manufacturer;

(b) short-time or intermittently rated motor runs continuously. Run the motor in the rated duty;

(c) core and windings are covered with heat-insulating dust. Blow down the machine with clean and dry compressed air at a pressure of up to 0.2 MPa taking measures to discharge the dust from the machine and not to displace it from one part to another;

(d) slant-blade fan rotates in the wrong direction. Reverse the fan rotation or change the position of its blades;

(e) cooling duct is insufficiently wide or bent at many

points. Take measures to increase the sectional area of the cooling duct and straighten the latter.

It may happen that *separate machine parts*, such as rotor or armature windings, field coils, commutator, brushes, stator stack and windings, slip rings, or some other parts get overheated. In every particular case it will be necessary to locate the cause of trouble of this very part if the cooling system is in good condition. In such an event, check all the contacts passing current to the part running hot, then measure the characteristics of the hot part circuit, such as current, voltage, speed, voltage drop, supply voltage and compare them with rated values. Causes of excessive temperature rise may be of various kinds. For instance, too slow speed at rated load impairs cooling conditions for the machine; incorrect sequence of main poles causes additional equalizing currents in the armature circuit; field current may rise to an inadmissible value because of a faulty regulator or other causes; turn-to-turn or earth fault in windings; short circuit through commutator bars; wrong connection of coil leads; too heavy reactive power of generator and, hence, excessive field current, etc. Upon detection of the cause of overheating the fault shall be eliminated. Manufacturer's representatives may be invited, if necessary.

Faults in air coolers may also cause overheating of the machine or improper cooling conditions. These faults are as follows:

Air cooler is clogged. As a result, the temperature difference between the inlet and outlet water increases. Remove the cooler lids and wash the cooler with a weak solution of hydrochloric acid.

Air cooler sweats:

(a) temperature of inlet water is below the dew point of cooling air. Raise water temperature by feeding back some portion of hot water;

(b) great amount of moist air is sucked into the cooling system from the machine room through loose joints. Seal all the joints in the machine and in the cooling system.

The air cooler is to be also checked for the following characteristics associated with the operating conditions: losses discharged by cooler, air flow rate, water flow rate, inlet water temperature, cooling air temperature, air pressure

gradient. Air flow rate is the most essential factor for the cooler. Insufficient air flow rate considerably impairs the cooler characteristics and decreases the efficiency of the entire cooling system.

The performance characteristics (no-load, short-circuit, control, speed-torque, loading, external, mechanical, starting, etc.) are to be taken during the no-load and on-load running of the machine depending on the machine type, application, operating duty, and particular operating conditions. For methods of taking characteristics or measurements and test techniques refer to special manuals for debugging personnel.

22.4. Vibration Tests of Machine Parts During Trial Starts. Causes of Vibrations and Measures to Be Taken During Installation of Machine to Prevent Them. Specified Values of Vibration

The machine is to be checked for vibration during the no-load and on-load trial start of the machine first by the feel of the hand. If vibration seems above normal, check it with a vibrometer or a vibrograph which have been described above.

Take separate measurements at every bearing and at other rotating parts of the machine. For variable-speed machines vibration shall be measured at every speed of the machine.

The vibrometer shall be operated in compliance with pertinent instructions furnished by the Manufacturer. It is common practice to set the vibrometer measuring stem in a position corresponding to the direction of vibration measurement (horizontal, vertical, etc.). The vibrograph is to be held in hands and does not require any additional support. Vibrations are recorded on a chart.

If vibration exceeds the specified values, locate the cause of trouble which may be misalignment of shafts, unbalanced coupling, insufficient mass or rigidity of foundation, loosely fastened bearing pedestals, uneven settlement of foundation, inaccurately levelled-off machine, excessive clearance between the shaft journals and bearing shells, not round shaft journals, distorted geometry of the shaft, unbalanced rotor,

etc. These are mechanical troubles. Electromagnetic troubles causing vibration may be as follows: nonuniform air gaps between the stator and rotor stacks, poor contact in rotor circuits, non-uniform magnetic field set up by the stator or rotor, etc. The cause of vibration is to be located by the method of exclusion of each cause. A fault detected shall be eliminated by methods used in the installation and tests of the machine. If vibration is caused by unbalanced rotating parts of a motor-generator set or non-uniform magnetic field built up by the stator or rotor, it will be necessary to apply to the Manufacturer. In the absence of specified values of vibration furnished by the Manufacturer, refer to the following data:

Machine speed, r/min	750 and lower	1000	1500	3000
Vibration, mm	0.16	0.13	0.1	0.05

CHAPTER TWENTY-THREE

Organization of Labour and Safety Precautions

23.1. Organization of Labour and Setting-up of Working Place

All constructional, installation and wiring jobs are carried out in the Soviet Union by specialized enterprises or by the facilities of the User. The relations between general building organizations (trusts) and the User or Investor are officially registered in the form of contract agreements. The general building organization (or General Contractor) enters in to contract relations with specialized organizations (Sub-Contractors) for carrying out the necessary jobs according to the contract with the User. The General Contractor is responsible to the User for the entire scope of building, installation and wiring jobs, quality and timely commissioning of the equipment installed.

Relations between Users and General Contractors are determined by "Rules for Building Construction Contract Agreements" and those between general Contractors and Sub-Contractors, by "Regulations for Relations between General Contractor Organization and Sub-Contractor Enterprise".

Organizations which have entered into contract relations bear a responsibility for the observance of the agreement.

Glavelectromontazh (the main electrical installation organization) is a complex organization which carries out design and research work, produces electric wiring and structural parts as well as installation and wiring tools and mechanisms, installs electrical equipment and sets up electric power systems, adjusts complex electrical machines and mechanisms, places the electrical equipment in operation.

Electrical equipment installation trusts are organized on the territorial principle. Each trust comprises a group of electrical equipment installation and wiring boards which are main self-supporting enterprises carrying out the insta-

llation work. The installation boards organize installation divisions and divisions of executives in charge to organize and carry out the work on the site of installation. For the installation of large electrical machines the boards organize special installation teams and divisions of executives in charge which improves quality and raises the productivity of labour.

The electrical equipment installation trusts include debugging boards which carry out the debugging, adjustment, and starting of installed electrical equipment in compliance with an agreement made directly with the User. This board renders, in addition, technical aid to the installation and wiring board in mounting large electrical machines, transformers, and other pieces of equipment.

A timely and thorough preparation of the working area for carrying out installation and wiring jobs is an important factor ensuring high quality and efficiency of these jobs. The preparatory operations include three main steps, *viz.*, preparatory (organization of manpower, inspection of objects handed over by builders and their acceptance for further installation work, etc.); preparation of materials and technical aids, such as mechanisms, fixtures, tools, instruments, gauges, safety facilities, etc.; working-out of the electrical equipment installation progress plan (IPP) and its practical application. Preparation of the working area is controlled by special departments of the board or by some other departments.

Premises meant for the installation of electrical machines must be accepted for the job which is to be officially registered in an acceptance report.

In order to prevent any disagreement between electricians, debugging staff, mechanics, plumbers, and other contractors involved in the job, the appropriate ministries and departments shall draw up special documents differentiating the work to be done by every contractor.

For instance, in the installation of electrical machines the work is differentiated as follows. All the electric motors incorporated in motor-driven mechanical units (compressors, fans, pumps, machine tools and mechanisms, etc.), with the exception of the main motors of rolling mills, are to be installed by organizations mounting the mechanical equipment,

Inspection and drying-out of electric motors must be carried out by electricians. When one of the motor bearings is used at the same time as the bearing of the driven mechanism, all the mechanical parts of the motor shall be inspected by the organization which has mounted the driven machine. Inspection, installation, and drying-out of independent generators, motor-generator sets, main motors of rolling mills, dc and ac machines shall be entrusted to electricians. Installation of electromagnetic and motor-operated brakes on mechanical pieces of equipment, electromagnetic drives, lubricating and hydraulic system valves is to be done by mechanical equipment installation enterprises.

All the pre-start electrical measurements and tests are made by the User of debugging staff. Forced lubrication and cooling systems of electrical machines are to be installed, adjusted, and placed in operation by contractors who installed these systems, but under the supervision and with the assistance of electricians.

Minor operations can be also discriminated according to their type and scope.

Organization of the working place is an essential operation for every member of the installation team. To this end, the following must be done. Efficient overall and local lighting shall be provided. The machine room shall be equipped with two or three vice benches furnished with boxes for small items and tools, one or two lockers for keeping waste material, rags, cotton pieces, cloths, as well as other auxiliary materials; a locking drawer to keep POLs, cans, pails, sprinklers, pans, etc. A storage of drills, hammers, slings, ropes, step-down transformers, small air compressors, and other tools and accessories shall be organized in the machine room. Premises for working with technical documents and reference drawings must be located in close proximity to the installation site. The premises must be equipped with desks, chairs, shelves for documents and reference books, and also with a drinking water tank, a cup, and a drug chest.

Organization of working place may include other operations and depends on the environmental conditions as well as on the size and number of machines to be installed.

A proper organization of labour includes convenient handling and correct storage of machines and their parts in the

vicinity of the installation site. The installation progress plan must include the following data essential for the particular conditions:

type and load-carrying capacity of cranes for hoisting and haulage of machines, number of cranes and their positioning;

rail tracks or roads and their location for dispatching machines to the installation site; cranes provided for unloading the machines from flat cars;

local intermediate rail tracks provided for delivering the machines to machine rooms on trucks;

mounting sites and hung floors with due account for permissible thrusts per 1 m^2 of the latter;

number of parts of electrical machines and standard equipment boxes (packages) according to identification Nos. indicated in the packing lists furnished by the Manufacturer.

Pre-installation location of electrical machine parts and boxes, and also freight traffic volume must be marked in the electrical equipment layout drawing to the scale of the drawing.

Upon arrival from the store room, the boxes with electrical machine parts shall be placed on specially prepared mounting sites near the foundation meant to receive them. The electrical machine parts must be arranged in strict compliance with the installation progress plan and in a sequence in which they are to be installed so as to avoid unnecessary haulage of these parts. Prior to installation, the installation Contractor, along with the User, must draw up a schedule of delivery of electrical machines and parts to the installation site to avoid the obstruction of the installation area with pieces of equipment which are not yet required.

A due organization of the installation process and working place will ensure an increase in the efficiency of labour, high quality of installation and timely commissioning of the electrical equipment.

23.2. Safety Precautions

All persons involved in the installation work must have certificates stating that they have passed yearly examinations on safety precautions.

Newly engaged personnel may be admitted to work only after they have passed a preliminary briefing on safety and sanitary rules as well as briefing on safety precautions directly on the site of installation, the latter being also given to all men who have changed their work or working conditions. The briefing must be repeated for all workmen once every three months, this being registered in a special log-book.

Basic safety precautions in the installation of electrical machines. When unpacking boxes with electrical machine parts, take care to avoid displacement and turning-over of these parts within the packing box. To this end, when unpacking the box, refer to the packing drawing or, in the absence of the latter, make a hole in the packing and examine fastenings inside the box. The sequence of unpacking, and the sequence of removal of bands and clamping bolts in particular, shall be stated by the engineer in charge of installation.

For handling electrical machines and their parts use parts specially meant for the purpose (they are usually shown in installation drawings furnished by the Manufacturer). The electrical machine parts shall be mounted on stages or hung floors in a stable position at a distance of not less than 1 m from the edge of the stage or hung floor.

Before cleaning and flushing the machine parts in alcohol, petrol, kerosene make sure that the room is equipped with appropriate ventilation and furnish respirator mouthpieces for all the men at work. In the process, see to it that no work with open flame is carried out nearby. Used waste shall be stowed away in an enclosed metal box to be then destroyed. Never turn down the commutator, nor grind it or slip rings without putting on protective goggles.

Make sure that pits and grooves around the machine are covered with planks.

In drying out or check heating of electrical machines, warm up the latter by covering them with nonflammable heat-insulating materials. Make sure that the electric air blowers are equipped with spark guards. Periodically ventilate the room where the machine is dried out. Earth the machine frame if it is to be dried out by electric current. Also earth the air blowers and electric ovens used for drying.

In driving the rotor into the stator, mounting the end shields, and turning the rotor refer to Manufacturer's instructions giving safety precautions on carrying out these operations.

Put on mittens before disassembling, reassembling, or installing the electrical machines on foundations or supporting structures.

Prior to giving the machine a trial start check the anchor bolts for tightness, the machine for foreign objects and for earthing.

Never eliminate any defects in the oil-cleaning equipment while the machine is running. Before eliminating any defect, cut off the general knife-switch and hang a notice: "Do not turn on, men at work!".

As soon as power cables or busbars are connected to the electrical machine terminals and to the switchgear cubicle which is in operation or fully wired and ready for use, it is forbidden to apply voltage to the machine or to carry out any installation or wiring jobs unless rules for operating working equipment are observed. The equipment is considered as working when it can be powered by turning on switching devices.

Basic safety precautions in handling the hoisting and haulage equipment. Assembly and disassembly of electrical machines, their erection on foundations or supporting structures involve the use of hoisting and haulage equipment mounted on or suspended over the site of installation. Hoisting machines are controlled from the cabin by a specially trained hoist operator who has a permission from the Owner to operate the machine. Floor-operated hoists may be controlled by workers briefed and trained in operating the machine, tying slings and hooking the loads according to adopted procedure.

Tying slings, ropes, and chains, as well as hooking the loads shall be entrusted to specially assigned slingers who have passed appropriate training and medical examination.

Parts whose mass approaches the limiting value shall be hoisted in two steps. First they are to be lifted to a height of 200 or 300 mm and examined in this position for proper slinging and for reliable setting of the crane, whereupon they can be lifted to the desired height. It is inadmissible to drag

the loads by obliquely tensioning the ropes or turning the boom.

Ropes cannot be used unless they are furnished with test certificates. Loops on steel-wire ropes and spliced ropes of tackle blocks must not be admitted. The loop at the end of the rope shall be made with a thimble secured in place by rivets or clamps. Worn-out or fraid strands in hemp ropes are inadmissible.

Electric hoists and hand-operated winches shall be equipped with gear drives. Belt or friction drives must not be admitted. Electric hoists with gear drives are to be furnished with electromagnetic brakes. Power-operated electric hoists and other mechanisms shall be earthed before use.

Hoist blocks must bear brands stating their load-lifting capacity.

Jacks shall be taken out from under a lifted item or shifted to another position after the item is reliably secured in the lifted position or placed on a stable supporting stack.

Rack-and-pinion jacks must be fitted with special devices to prevent spontaneous movement of the load downwards as soon as the force is removed from the rack or handle. The screw and rack-and-pinion jacks must have locking devices holding the screw or rack in position. Hydraulic jacks must be equipped with a special arrangement (non-return valve) to ensure a slow and smooth lowering of the rod in the event of faulty fluid supply pipes.

Heavy and important pieces of equipment shall be handled under the supervision of a specially assigned engineer.

Fastening chains, ropes, slings, hoists, and other auxiliary load-carrying facilities shall be examined and tested by a duly qualified person at predetermined intervals and in full compliance with appropriate regulations and safety rules. Table 23.1 specifies standards and intervals of inspections and tests for hoists, outfits and accessories.

Hoists and load-carrying facilities shall bear escutcheon plates or labels indicating their serial number and date of test to be carried out.

Basic safety precautions for debugging operations. Debugging of electrical equipment should be entrusted to persons who have been given a medical check-up, have passed an examination before a qualification board and got a safety

Table 23.1

Standards, Inspection and Test Intervals for Hoisting Mechanisms and Associated Equipment

Hoist, equipment	Test load, kgf			Static test duration, min	Intervals	
	at acceptance test and after major repairs		at periodic static tests		test	inspection (with entries made in log-book)
	static	dynamic				
Hand-operated winches	$1.25P_{rated}$	$1.1P_{rated}$	$1.1P_{rated}$	10	Once every 12 months	—
Electric hoists	$1.25P_{rated}$	$1.1P_{rated}$	$1.1P_{rated}$	10	Once every 12 months	—
Tackle blocks, trucks, cranes	$1.25P_{rated}$	$1.1P_{rated}$	$1.1P_{rated}$	10	Once every 12 months	—
Pulley blocks, compound blocks	$1.25P_{rated}$	$1.1P_{rated}$	$1.1P_{rated}$	10	Once every 12 months	Once every 6 months
Screw jacks	$1.25P_{rated}$	$1.1P_{rated}$	—	—	—	Once every 3 months
Miscellaneous jacks	$1.25P_{rated}$	$1.1P_{rated}$	$1.1P_{rated}$	10	Once every 12 months	—
Chains	$1.25P_{rated}$	—	$1.1P_{rated}$	10	Once every 6 months	Once every 10 days
Steel-wire ropes	$1.25P_{rated}$	—	$1.1P_{rated}$	10	Once every 6 months	Once every 10 days
Hemp, cotton, capron ropes	$1.25P_{rated}$	—	$1.1P_{rated}$	10	Once every 6 months	Once every 10 days
Slings of all types	$1.25P_{rated}$	—	$1.1P_{rated}$	10	Once every 6 months	Once every 10 days
Lifting beams, rocker arms	$1.25P_{rated}$	—	$1.1P_{rated}$	10	After repairs	Once every 6 months

qualification certificate, have been given preliminary and in-situ briefings, familiarized themselves with sanitary and personal hygiene rules, have studied the electrical equipment debugging technique.

Prior to commencing the debugging operations, the person in charge of debugging shall familiarize all the members of the team with reference drawings showing the electric circuitry and layout of machines and associated equipment.

The person in charge of debugging is responsible for the observance of safety precautions by all the members. Every day before the work is started he must check the arrangement of guards and warning notices, and make sure that dangerous voltages are not applied at places where men are to work.

Debugging of electrical pieces of equipment must be performed by at least two persons one of them being of at least group IV qualification (when dealing with equipment rated over 1000 V) or group III qualification (when debugging a piece of equipment rated up to 1000 V).

Protective aids shall be tested in compliance with "Rules for Application and Tests of Protective Aids Used in Servicing Electrical Equipment".

All persons carrying out debugging jobs involving the use of voltage exceeding 12 V in hazardous atmospheres or 36 V in normal conditions shall wear rubber shoes.

Prior to taking measurements of the insulation resistance with the aid of a megger it is necessary to make sure that nobody is working on the part of equipment to be tested.

Insulation resistance measurements in branched-off circuits where some sections are out of sight of the executive in charge shall be carried out by at least two persons, one of them having at least group IV qualification. Sections which are out of reach of the executive in charge must be watched or furnished with warning notices: "Stop! High voltage!"

Prior to connecting a measuring instrument to the winding whose insulation resistance is to be measured and after the measurements are completed, the winding shall be discharged through a special discharge rod.

Basic safety precautions in operating power-driven tools and in electric welding. Working places elevated one meter or more above the ground or floor shall be guarded with barriers or wire-net with a hand-rail. The barriers or hand-

rails must withstand a load of 70 kg. When the working place is elevated over 1.5 m above the ground or floor (classified as overhead work), and over 5 m in particular (classified as steeple work), it is essential that respective safety rules be observed; when working on non-guarded areas, use must be made of a duly checked and tested safety strap having a certificate and a label, etc.

Power- and air-driven tools shall be operated by personnel specially trained in the rules of safety and having a note in the safety qualification certificate. Power-driven tools must either have reinforced (double) insulation or be rated not over 36 V. Where the danger to human life is not so great, they can be rated over 36 V. In the latter case the tool body shall be earthed and before using the tool it is necessary to put on rubber gloves and shoes.

Operation with propane-butane gas and torches is to be entrusted to persons who have been trained in safety precautions and get appropriate certificates.

The wire pistol shall be operated by the most disciplined and competent electricians (men) who have passed a medical check-up, have graduated from a special course and issued a certificate stating that they may operate the pistol.

Welding jobs and servicing of welding equipment must be entrusted to persons specially trained in safety precautions and given appropriate certificates.

Electricians in charge of installation of electrical machines must be well acquainted with safety precautions in mounting and wiring lighting circuits and power systems and also with rules for servicing the working electrical equipment.

First aid to victims of electric shock. In the event of electric shock, an ambulance must be called for without delay or the victim shall be dispatched to a hospital. While the doctor has not yet arrived or the victim has not been dispatched to a hospital, he must be given first aid on site. The first thing to do is to free the victim from contact with live parts taking necessary precautions so as not to add another victim to the accident. In other words, the electrical equipment shall be switched off or use be made of rubber shoes, gloves, mats, dry wood, or the victim be gripped through a dry material and torn off the source of electric current.

If an accident has taken place at a high voltage, it is necessary to put on dielectric boots and gloves and to use a rod.

Artificial respiration shall be started without delay in all cases where normal breathing has been stopped or is weak and shall be continued uninterruptedly until recovery (which may sometimes take over 4 hours) or until there are positive evidences of death (*livores mortis*). The most efficient is "mouth-to-mouth breathing" method. To render first aid by this method, take a deep breath twice or three times whereupon breathe air into the mouth of the victim laid flat on his back through a special tube, a piece of gauze or cloth. Make 12 to 15 artificial respirations per minute. Expiration takes place as a result of contraction of the patient's chest. When air is breathed in, the victim's chest must expand. If it does not, check his head and tongue for a correct position. Pull the tongue forward and toward the chin and hold it in this position by hands, with the aid of pins, needles or other holding devices.

It may happen, however, that artificial respiration alone cannot revive the victim of electric shock.

Efficient resuscitation can be obtained by an indirect chest massage made in conjunction with artificial respiration. To this end, one of the revivers shall put one of his hands on the bottom part of the victim's breast bone and with the other hand quickly push on the first hand so as to shift the breast bone over 3 or 4 cm. After three or four such pushes an interval of 2 s must be made while air is breathed in and just started to escape. Then the pressure on the breast bone is to be repeated. If a single man renders first aid, he must first make two or three deep inhalations followed by a 15-20 s indirect chest massage and then another two or three deep inhalations. Each push on the chest is accompanied by pulsations in the major arteries.

Another method of artificial respiration uses the following technique: place the patient in the face-down position with one bent arm underneath and the other arm extended directly forward having placed a pad under his face. Kneel astride the patient facing him so that his thighs are between your knees. To the count of "one, two, three" gradually push the lower ribs of the patient with your hands, then swing back-

wards to the count of "four, five, six" and push the lower ribs again to the count of "one, two, three".

There is still another method of artificial respiration. The patient is placed on his back. A small pad should be placed under his back, just below his neck, so that the head is slightly extended. One of the operators forces the patient's mouth open, draws out his tongue and holds it in this position. The other operator kneels near the head and grasps the patient's arms immediately below the elbows and presses them against the sides of the chest to force the air out of the lungs. To the count of "one, two, three" he draws the patient's arms vertically and then headward, thus allowing the lungs to fill with air. To the count of "four, five, six", he brings the patient's arms back and presses them to the chest, the cycle being repeated as long as necessary.

Chances of recovery depend on how promptly and efficiently resuscitation was administered. Therefore, all the electricians and debugging personnel must know how to administer artificial respiration and indirect chest massage to the victims of electric shock.

Appendix 1

Technical Documents to Be Filled In when Handing Over and Accepting Large and Medium-Size Electrical Machines after Installation

Form No. 5

ACCEPTANCE REPORT

on the condition of foundation (supporting structure) made ready to start installation of equipment

Town ______________ "____" ______________ 19____

Enterprise (User) ______________________________

Shop (site) ______________________________

We, the undersigned, representative of

____
(name of building Contractor)

in the person of ______________________________
(position, name)

representative of ______________________________
(name of installation Contractor)

in the person of ______________________________
(position, name)

and User's engineering supervisor in the person of

____
(position, name)

state herewith that the foundation (supporting structure) for the installation of ______________________________
(name of equipment)

has been made to drawing of ______________________________
(No. and name of Designer)

in full compliance with design dimensions and is acknowledged as ready for installation of mechanical and electrical equipment.

Special notes ______________________________

____

Appendices 1. Foundation Service Log
2. Surveying scheme (authorizing document)

____

3. ______________________________
4. ______________________________

Representative of building Contractor ______________________________

Representative of installation Contractor ______________________________

User's engineering supervisor ______________________________

Appendix 2

Form No. 60

Forms of Handing-Over Documents

Town __________________

User __________________

Installation site ____________

Location ____________

Date " " 19

REPORT No.________

on machine to be subjected to inspection involving its disassembly

We, the undersigned, on the panel of User's official

____________ (name), installation Contractor's official

________________ (position, name), upon having examined the

____________ current $\frac{\text{motor}}{\text{generator}}$, type ____________,

output__________ kW, voltage__________V, Serial No.________

speed __________ r/min, declare herewith that the machine is subject to inspection in a disassembled condition, the reasons

being ________________________ (brief description of reasons)

The inspection of the machine involving its disassembly is entrusted

to ________________ (executive in charge) by the order of ________________ (ordering agency)

who is to supply the executive in charge with all necessary technical documents which can be furnished by the Manufacturer.

User's official *Installation Contractor's official*

Appendix 3

Form No. 62

Town ____________________
User ____________________
Installation site ____________
Location ___ . ____________
Date "_____" ________ 19

INSPECTION AND TEST REPORT No. ________

on large or medium-size electrical machine dispatched in a disassembled condition

I. Electrical Machine Technical Data

Where installed (equipment or drive)	Type and design form	Manufacturer	Serial No.	Date, manufactured	Output, kW	Voltage, V	Speed, r/min

II. Condition of Stator and Rotor

Component	Stator	Rotor
1. Core 2. Cooling ducts between stacks 3. Slot wedges 4. Metal bands (insulation to rotor or armature) 5. Cord bands 6. Commutator, slip rings, short-circuiter 7. Leads and binding posts		

III. Condition of Windings and Insulation Resistance

Winding	External inspection results and faults detected	Insulation resistance, M, at $t =$ °C
8. Stator winding		
9. Rotor winding		
10. Starting (squirrel-cage) winding		

IV. Condition of Bearings

Description	Front bearing	Rear bearing
11. Bearing pedestals		
12. Bearing shells		
13. Oil-level indicators, drain plugs		
14. Lubricating rings		
15. Labyrinth seals		
16. Insulating gaskets		
17. Shaft journals		

V. Condition of Brush Rigging

18. Brush rocker ____________, insulation resistance ____________ M

19. Brush holders ____

20. Brushes ____

VI. Condition of Cooling System

21. Fastening of fans or fan blades ______________________________

Faults remedied ____

Statement ____

Insulation resistance has been measured with a ___________V megger,

type _________, scale range __________, Serial No. ____________

Examined and tested by ____________________________________

Engineer in charge, foreman ________________________________

User's official ____

Appendix 4

Form No. 63

Town ____________
User ____________
Installation site ____________
Location ____________
Date "______" ____________ 19____

REPORT No.________
on electrical machine drying

1. Electrical Machine Technical Data

Application of machine	Manufacturer	Serial No.	Type and design form	Date, manufactured	Output, kW	Speed, r/min	Stator		Rotor	
							voltage, V	current, A	voltage, V	current, A

2. Brief description of drying method used (induction heating, heating by external current source, by short-circuit current, by air blower), points temperature was measured at, basic specifications of drying equipment, data on heating winding and drying circuit arrangement.
3. Insulation resistance of cold windings at ________ °C ________
4. Drying started ________________ ceased ________________
5. Drying log

Date and hours	Temperature, °C						Insulation resistance					Heat source		Executive in charge, name and signature
	ambient	points of measurement				outlet air (with machine running)	ac machine					temperature at oil blower outlet, °C	current, A	
							stator			rotor				
							1	2	3					
							dc machine							
		1	2	3	4		armature	commutating poles	series windings	shunt windings				

The insulation resistance has been measured with a ________ V megger, type ________, Serial No.________, scale range ________
The temperature has been measured ________________
Statement ________________

Person in charge of drying ________________

Appendix 5

Form No. 64

Sheet 1

Town ____________________

User ____________________

Installation site ______________

Location ____________________

Date "______"____________ 19 ____

SERVICE LOG No.____________

Installation and wiring data on large electrical machine (motor-generator set) dispatched in a disassembled condition

1. Technical Data on Machine (Motor-Generator Set)

Where installed (equipment or drive system)	Machine type and design form	Manufacturer	Serial No.	Date, manufactured	Output, kW	Voltage, V	Speed, r/min

2. Installation of bed plate

For the layout of reference points on the bed plate and survey bench marks indicating these points refer to Sketch 1.

3. Position of shafts

For the readings of a level set on the shaft journals and the values of end plays of shafts refer to Sketch 2.

4. Alignment of shafts

The half-coupling is mounted on the shaft by________method.

For clearances to be provided in half-couplings during the alignment of shafts refer to Sketch 3.

5. Bearings

For clearances under bearing shells and caps, those between the shaft and labyrinth seals and also for values of vibration refer to Sketch 4.

6. Air gaps

For the results of air gap measurements refer to Sketch 5.

Appendix 6

Form No. 63

Sheet 2

Town ____________

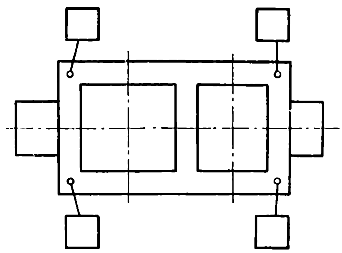
User ____________

Installation site ____________

Location ____________

Date "___" ________ 19 ____

TYPICAL EXAMPLE OF SKETCH 1



Survey bench marks of reference points on bed plate

Checked by ____________

Engineer in charge, foreman ____________

Appendix 7

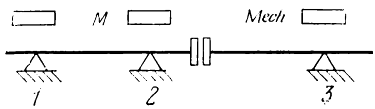
Form No. 64
Sheet 4

Town ______________________
User ______________________
Installation site ______________ A
Location ______________________
Date "______" ________ 19______

TYPICAL EXAMPLE OF SKETCH 2 TO THE SERVICE LOG

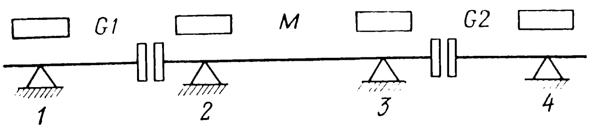
I. Levelling of shafts

1. Two-machine set



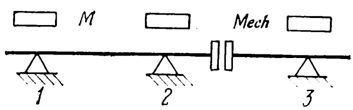
M — motor; *Mech* — driven mechanism; *1*, *2*, *3* — bearings

2. Three-machine set



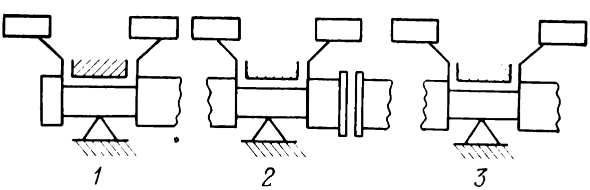
*G*1, *G*2 — generators; *M* — motor; *1*, *2*, *3*, *4* — bearings

3. Motor and driven mechanism



M — motor; *Mech* — driven mechanism; *1*, *2*, *3* — bearings

II. Axial play of shaft



1, *2*, *3* — bearings

Checked by ______________
Engineer in charge, foreman

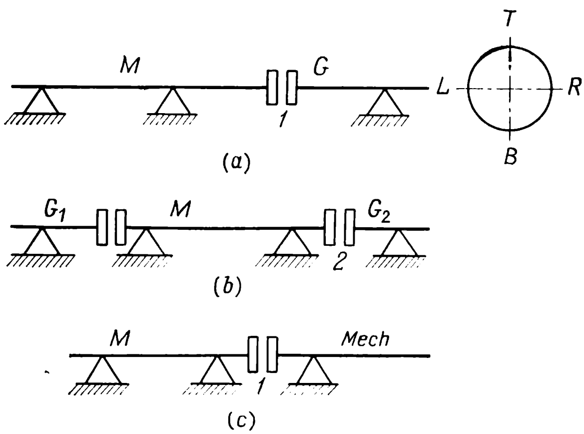
Appendix 8

Form No. 64

Sheet 4

Town ____________________
User ____________________
Installation site ____________
Location ________________
Date "______" __________ 19 ____

TYPICAL EXAMPLE OF SKETCH 3 TO THE SERVICE LOG



Alignment of machine shafts
(*a*) two-machine set; (*b*) three-machine set; (*c*) motor and driven mechanism

Alignment of machine shafts

Appendix to Form No. 64 (Sketch 3)

Set	Half-coupling No.	Clearances between half-couplings, mm							
		axial				radial			
		B	*H*	Б$_1$	Б$_2$	*B*	*H*	Б$_1$	Б$_2$
Two-machine set	1								
Three-machine set	1								
Motor and driven mechanism	1								

Checked by ____________________

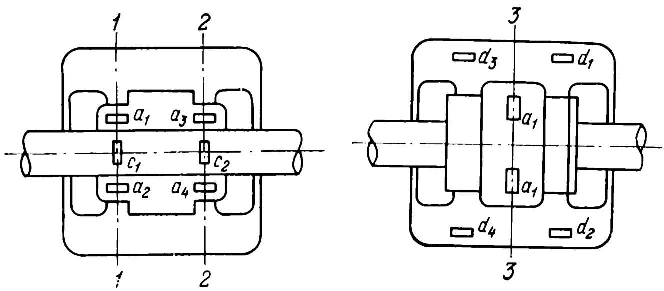
Engineer in charge, foreman ____________

Appendix 9

Form No. 64
Sheet 5

Town ______________
User ______________
Installation site ______________
Location ______________
Date "______" ______________ 19____

TYPICAL EXAMPLE OF SKETCH 4



Bearing clearances and vibration
a— clearances between shaft journal and bearing shell (at planes *1-1* and *2-2*); *b*—clearance between bearing shell and cap (at plane *3-3*)

Bearing clearances, insulation resistance of bearing pedestals, and vibration on bearings

Appendix to Form No. 64 (Sketch 4)

Clearance, mm	Bearing No. 1	2	3	4	Equations to determine average values of clearances
k_1					$k_1 = c_1 - \frac{a_1 + a_2}{2}$
k_2					$k_2 = c_2 - \frac{a_3 + a_4}{2}$
A					$A = A_1 - \frac{d_1 + d_2 + d_3 + d_4}{4}$
Vibration, mm					
Insulation resistances of bearing pedestals, M					

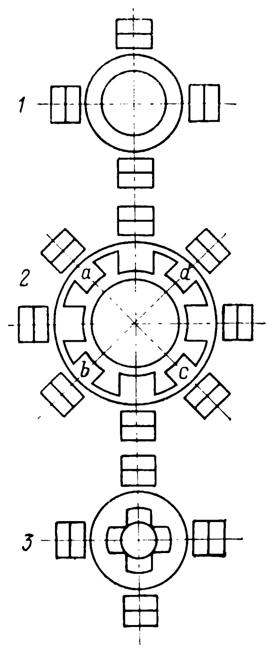
Checked by ______________
Engineer in charge, foreman ______________

Appendix 10

Form No. 64
Sheet 6

Town ____________________
User ____________________
Installation site ____________
Location __________________
Date "_____"__________ 19 ____

TYPICAL EXAMPLE OF SKETCH 5



Air gaps

1 — induction motor; 2 — dc machine; 3 — synchronous machine

Checked by ____________________
Engineer in charge, foreman ________________

Appendix 11

English Equivalents of Russian Fits

Russian designation	Description	English equivalent (approximate)
Гр	Force fit	FN4 and FN5
Пр	Heavy drive fit	FN3
	Medium drive fit	FN2
П	Light drive fit	FN1
Г	Locational clearance fit	LC
Т	Locational transition fit	LT
Н	Locational interference fits	LN
С	Close sliding fit	RC1
	Sliding fit	RC2
Д	Precision running fit	RC3
	Close running fit	RC4
Х	Medium running fits	RC5 and RC6
	Free running fit	RC7
ТХ	Loose running fits	RC8 and RC9

Index

TO THE READER

Mir Publishers welcome your comments on the content, translation and design of the book.

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